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LIST OF PUBLICATIONS.

DOUGLASS HOUGHTON, State Geologist.

Reports from 1838-1846 were published with Legislative documents as follows: S. D. means Senate documents; H. D., House documents; J. D., joint documents. State Geologist is abbreviated S. G., and State Geological Survey, S. G. S.

1838. Report of a select committee of the Board of Regents of the University on the collection of the S. G.
H. D. Vol. I, p. 1-2; S. D. No. 1, p. 1. H. D. No. 55 is duplicate of No. 1.
Statement of the expenditures on account of the S. G. S. for the year 1837.
H. D. No. 8, pp. 115-118; S. D. No. 21 (First annual account of the S. G.), pp. 315-318.
Report of the S. G. (first annual).
H. D. No. 24, pp. 276-317; S. D. No. 16; separately, No. 14, pp. 1-39.
Communication from the S. G.
H. D. No. 46, pp. 457-460.
1839. Report of the S. G. in relation to the improvement of State Salt Springs.
H. D. No. 2, pp. 39-45; S. D. No. 2, pp. 1-8.
Report of the committee on the S. G.'s report in relation to the improvement of the State Salt Springs.
H. D. No. 4, pp. 123.
Report of the S. G. in relation to the iron ore, etc., on the school section in town five south, range seven west, in Branch county.
H. D. No. 21, pp. 342-344.
Second annual report of the State Geologist.
H. D. No. 23, pp. 380-507; S. D. No. 12, pp. 264-391; also separately H. R. No. 23, and S. R. sometimes misprinted No. 13 and No. 23, pp. 39 and appendix of sub-reports 123 pp.
Report of the Committee of the Senate on Manufactures, to whom was referred the communication of the S. G. relative to salt springs and the salines of the State.
S. D. No. 3, pp. 85-86 (parallel to H. D. No. 4).
Communication from the S. G. relative to the G. S.
S. D. No. 26, pp. 463-466; J. D. No. 3, app.
1840. Report of S. G. relative to the improvement of the Salt Springs.
H. D. No. 2, Vol. I, pp. 18-23; S. D. No. 8, Vol. II, pp. 153-158.
Annual report of the State Geologist (third, map of Wayne county).
H. D. No. 27, Vol. II, pp. 206-293; S. D. No. 7, Vol. 2, pp. 66-153; separately H. R. No. 3, pp. 1-124.
Report of the select committee to whom was referred the several reports of the S. G.
H. D. No. 46, Vol. II, pp. 455-461.
Report of the majority of the Committee of Finance on the communication and accounts of the S. G. for 1839.
Report of the minority of the Committee on Finance on the same subject.
Report of the select committee on S. G.'s report and accounts relative to improvement of Salt Springs, etc.
S. G.'s account for the year 1839, the same being the subject matter of the three preceding reports.
S. D. No. 15, 16, 17, 18, pp. 209-224.
1841. Special message concerning State Salt Springs.
H. S. and J. D. No. 5, pp. 235-264.
Annual report of the S. G. (fourth).
H. S. and J. D. No. 11, pp. 472-607; separately H. D. No. 27, pp. 1-184; S. D. No. 16, pp. 1-184.
Report of the S. G. relative to county state maps.
H. D. No. 35, pp. 94-98.
1842. Report of the S. G. relative to the State Salt Springs.
H. D. No. 2, pp. 15-21; S. D. No. 1, pp. 1-9.
Report of the select committee in relation to the report of the S. G.
H. D. No. 19, pp. 77-79.
Annual report of the S. G. (fifth).
H. D. No. 14, p. 6; J. D. No. 9, pp. 436-441.
1843. Annual report of S. G. (sixth).
H. D., S. D., and J. D. No. 8, pp. 398-402.
Report of the S. G. relative to the State Salt Springs.
S. D. No. 9, pp. 402-408.
1844. Annual report of the S. G. (seventh).
S. D. No. 11 (three pages).
Maps of Washtenaw, Calhoun, Jackson and Lenawee counties were published separately.
1846. Report from Geological Department by S. W. Higgins, principal assistant.
J. D. No. 12, 22 pp.
Report of the joint committee relative to the Geological Survey.
J. D. No. 15, 8 pages.

A. WINCHELL, State Geologist.

1861. First biennial report of the progress of the G. S. of M. Embracing observations of the Geology, Zoology and Botany of the Lower Peninsula. Made to the Governor, Dec. 31, 1860.
The Walling Tackabury State Atlas contains a paper with geological and topographic maps by A. Winchell, reprinted separately under the title "Michigan."
1869. Report of the Joint Committees on Geological Survey, made to the Legislature of Michigan, Lansing, W. S. George & Co., Printers to the State, pp. 1-15.
1871. Report of the progress of the S. G. S. of M., pamphlet, pp. 1-64.
1873. Vol. 1. Upper Peninsula, 1869-1873. Accompanied by an Atlas of maps. Edition 2,000.
Part I. Iron Bearing Rocks (Economic), T. B. Brooks. Of this an extra edition of 500 with thirteen accompanying atlas plates (1 to 13, No. 2 is misnumbered 11) was issued.
Part II. Copper Bearing Rocks, Raphael Pumpelly (Plates 14, 14a 15-23 of the atlas accompanying; Chapters IV, VII, VIII are by A. R. Marvine).
Part III. Palaeozoic Rocks, Dr. C. Rominger. (Plate 24 of the Atlas accompanies. There was an extra edition of 500 dated 1872, without map or index, differing slightly in title page, introduction and paging).

1873. Vol. II. Upper Peninsula. 1868-1873, appendices to Part I, Vol. I. A. Lithology by A. A. Julien, B. Lithology by T. B. Brooks and A. A. Julien, C. Lithology by Charles E. Wright, D. Ore deposits, E. Lithology (Notes by D. Houghton), F. Iron ore dock (by Jacob Houghton and Chas. H. Palmer, with Plate 20), G. Census statistics (1870), H. Magnetic Analyses (by F. B. Jenney), I. Mining laws (by C. D. Lawton), J. Metallurgical qualities by H. B. Tuttle, K. Contortions of Laminæ (by T. B. Brooks).

C. ROMINGER, State Geologist.

1876. Vol. III. Lower Peninsula. 1873-1876, accompanied by a geological map. Edition 2,000.

Part I. Geology of the Lower Peninsula, by C. Rominger.

Appendix A. Observations on the Ontonagon Silver Mining District and the State Quarries of Huron Bay, by C. Rominger. B. Report on the Salt Manufacture of Michigan, by S. S. Garrigues, Ph. D., State Salt Inspector.

Part II. Paleontology. Fossil corals, by C. Rominger (with 55 plates).

1881. Vol. IV. Upper Peninsula. 1878-1880, accompanied by a Geological map. (Edition 2,000.) Part I. Marquette Iron Region. Part II. Menominee Iron Region, by C. Rominger.

See also Vol. V, Part I.

See also reports by Brooks, Pumpelly and Wright in the reports of the Wisconsin Geological Survey.

C. E. WRIGHT AND M. E. WADSWORTH, State Geologists.

See Vol. II and Vol. V, also the reports of the Commissioners of Mineral Statistics and the following entry:

1893. Report of the State Board of Geological Survey for the years 1891 and 1892, to which are appended exhibits setting forth the Expenses of the Survey from its inception to November, 1892, Exclusive of the Cost of Publication. Also the Reports of Dr. Carl Rominger for the years 1881-2; of Mr. Charles E. Wright for the years 1885-8; of Dr. M. E. Wadsworth for the years 1889, 1890, 1891, 1892, made to the State Board of Geological Survey for the years named; also a Provisional Report by Dr. M. E. Wadsworth, State Geologist, upon the Geology of the Iron, Gold and Copper Districts of Michigan.

L. L. HUBBARD, State Geologist.

1895. Vol. V. Upper Peninsula, 1881-1884; Lower Peninsula, 1885-1893. (Edition 2,500.)

Prefatory Historical Note by L. L. Hubbard.

Part I. Geological Report on the Upper Peninsula of Michigan, exhibiting the progress of work from 1881-1884. Iron and Copper Regions, by C. Rominger, accompanied by a map and two geological cross-sections.

Part II. The geology of lower Michigan, with reference to deep borings. Edited from notes of C. E. Wright, late State Geologist, by Alfred C. Lane, Assistant State Geologist, with an introduction on the origin of salt, gypsum and petroleum, by Lucius L. Hubbard, and accompanied by seventy-three plates and a map.

1899. Extracts from the annual reports of the State Geologist of Michigan, Lucius L. Hubbard, for the years 1897-1898. (By an error in Lansing this report really contains only the report for 1898. Edition 500.)

Vol. VI. Upper Peninsula, 1893-1897 (edition 954 and 200 of each part privately printed).

Part I. Geological Report on Isle Royale, Michigan, by Alfred C. Lane, Assistant State Geologist. Accompanied by 16 plates and 29 figures, including map in cover.

Part II. Keweenaw Point, with particular reference to the felsites and their associated rocks, by Lucius L. Hubbard, State Geologist. Accompanied by 10 plates and 11 figures.

Part II. Appendix. The crystallization of the calcite from the copper mines of Lake Superior, by Charles Palache. Accompanied by six plates (100 extra printed separately).

ALFRED C. LANE, State Geologist.

Coal in Lower Michigan, by Alfred C. Lane, published serially in the Michigan Miner, Vol. I, Nos. 3 to 10, February to September, 1899, (500 reprints).

1900. Annual Report for the year 1899. Michigan Miner, Vol. II, No. 3, February, 1900 (500 reprints stitched in with the following No.).

The Origin, Properties and Uses of Shale, by H. Ries, Special Agent for the State Geological Survey.

Preliminary, unofficial, see Vol. VIII, Part I. Published in the Michigan Miner, Vol. I, No. 12, Vol. 2, Nos. 1 and 3 (500 reprints).

Vol. VII. Lower Peninsula. 1893-1899. (Edition 1,500 and 500 of each part issued separately).

Part I. Geological Report on Monroe County, Michigan, by W. H. Sherzer. Accompanied by 17 plates and 8 figures, including three colored maps.

Part II. Geological Report on Huron County, Michigan, by Alfred C. Lane, accompanied by 11 plates, 12 figures and one inserted table, including two colored maps. (100 extras of Chapter IX, X §2, and X §3).

Part III. Geological Report on Sanilac County, Michigan, by C. H. Gordon, accompanied by 5 plates and 2 figures, including one colored map.

Vol. VIII. Economic Geology, 1899. (edition 1,500, 500 of each part bound separately).

Part I. Clays and Shales of Michigan, their Properties and Uses, by H. Ries, Accompanied by four plates and six figures.

1901. Annual Report for the year 1900. Michigan Miner Vol. III, Nos. 2 and 3 (Reprints furnished and issued by State Board.)

1902. Vol. VIII. Part II. Coal in Michigan, its Mode of Occurrence and Quality, by Alfred C. Lane, accompanied by nine plates and nine figures, including one colored map.

Report of the State B. of G. S. for the year 1901. seven figures, fifteen plates and maps. (Edition 1,500, reprints 200 each, of numerous papers.)

1903. Report of the State B. of G. S. for the year 1902. (Edition 500, reprint from Michigan Miner, Vol. V, No. 2.)

Vol. VIII, Part III, Marl (Bog lime) and its Application to the Manufacture of Portland Cement, by David J. Hale and others, accompanied by 23 plates and 43 figures, including one colored map.

GEOLOGICAL SURVEY OF MICHIGAN
LOWER PENINSULA

1900-1903

VOL. VIII

PART I. CLAYS AND SHALES, H. RIES

PART II. COAL, A. C. LANE

PART III. MARL [BOG LIME], D. J. HALE

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GEOLOGICAL SURVEY OF MICHIGAN

ALFRED C. LANE, STATE GEOLOGIST

VOL. VIII

PART I

CLAYS AND SHALES

OF

MICHIGAN

THEIR PROPERTIES AND USES

BY

H. RIES

ACCOMPANIED BY FOUR PLATES AND SIX FIGURES

PUBLISHED BY AUTHORITY OF THE LAWS OF

MICHIGAN

UNDER THE DIRECTION OF

THE BOARD OF GEOLOGICAL SURVEY

LANSING

ROBERT SMITH PRINTING CO., STATE PRINTERS AND BINDERS

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OFFICE OF THE STATE GEOLOGICAL SURVEY, }
LANSING, MICHIGAN, Sept. 15, 1900. }

To the Honorable, the Board of Geological Survey of Michigan:

{ HON. HAZEN S. PINGREE, *President*.
HON. PERRY F. POWERS.
{ HON. JASON E. HAMMOND, *Secretary*.

GENTLEMEN—Herewith I transmit as Part I of Vol. VIII, a report by Dr. H. Ries of Cornell University containing the results of his examination of the clays and shales of the State in the summer of 1899, and his tests upon them last winter.

Although it does not pretend to be exhaustive in its description of the wealth of the state in these abundant materials, it seems to me to give a clear description of the more important and common kinds, and an interesting account of the uses to which they may be put. I trust it may prove of value.

With great respect I am your obedient servant,
ALFRED C. LANE,
State Geologist.

TABLE OF CONTENTS.

CHAPTER I.

PROPERTIES OF CLAYS AND SHALES.

	Page.
§ 1. Origin of clay	1
§ 2. Physical properties	2
§ 3. Slaking	2
§ 4. Plasticity	3
§ 5. Behavior under heat	4
§ 6. Shrinkage	5
§ 7. Color	5
Color of the burned shale	6
Color of burned clay	6
§ 8. Tensile strength	6
§ 9. Chemical properties	7
§ 10. Alkalies	8
Efflorescence on bricks	8
§ 11. Iron oxide	10
§ 12. Lime	11
§ 13. Magnesia	11
§ 14. Silica	11
§ 15. Titanium	11
§ 16. Organic matter	12
§ 17. Water	12
Moisture	12
Combined water	12
§ 18. Minerals in clay	13

CHAPTER II.

USES OF CLAY AND SHALE.

§ 1. Clay products	15
§ 2. Common brick	15
§ 3. Front brick	15
§ 4. Manufacture of brick	16
§ 5. Paving brick	18
§ 6. Terra cotta	18
§ 7. Pottery	18
§ 8. Fire brick	19
§ 9. Portland cement	19
§ 10. Mineral paint	19
§ 11. Road material	19
§ 12. Slip clays	19

CHAPTER III.

TESTS.

	Page.
§ 1. Introduction	21
§ 2. Methods of testing	22
Pyrometric cones	22
§ 3. Prospecting for clays	24
§ 4. Geology of shale deposits	25
§ 5. Coal measure shales	25
Owosso	27
Owosso under clay	27
St. Charles	28
Verne	29
Flushing	29
Saginaw	30
Bay City	34
Jackson	37
Sebewaing	37
Grand Ledge	37
§ 6. Michigan series of shales	39
Grand Rapids	39
§ 7. Coldwater shales	41
Union City	41
Quincy	42
Coldwater	42
Bronson	43
White Rock	44
§ 8. Devonian shales	45
East Jordan	45
Norwood	46
§ 9. Hamilton (Traverse) shales	47
§ 10. Hudson river shales	48
§ 11. Surface clays	48
Detroit clays	49
Monroe county	51
Ionia	51
Harrietta	53
Saginaw	54
Clare county	55
Kalamazoo	56
Lansing	56
Sebewaing	59
Jackson	60
Rockland	60
§ 12. Analyses from miscellaneous localities. L.....	61
§ 13. Conclusion, by Alfred C. Lane	62

LIST OF ILLUSTRATIONS.

PLATES.

	Page.
I. Exposures of Coldwater shales along the shore of Lake Huron, near Forestville, and 2½ miles north thereof.....	44
II. Clay banks near Ionia	52
III. Clay bank and brickyard at Kalamazoo.....	56
IV. Sebewaing brickyard, washing tank and settling tank.....	60

FIGURES.

1. Molding bricks on auger machine, with triple die, Ionia.....	17
2. Shale quarry of Saginaw Clay Manufacturing Co., Flushing.....	29
3. Brick works of Saginaw Clay Manufacturing Co., Saginaw.....	31
4. Shale and gypsum quarry (in the Michigan series) of the Alabastine Co., near Grand Rapids	39
5. Near view of Clippert & Spaulding's clay bank, east of Lansing.....	57
6. General view of Clippert & Spaulding's clay bank, east of Lansing.....	58

ERRATA.

Page 50, line 6 from the bottom, at end of line read 6%.

Page 50, line 12 from the bottom, for drawers read dryers.

CHAPTER I.

PROPERTIES OF CLAY AND SHALE.

§ 1. Origin of clay.

Clay is a familiar material and known chiefly by the curious property which it has of forming a pasty or plastic mass when mixed with water, allowing itself to be molded into any desired shape. It is mostly a fine, aluminous sediment that has been deposited on the bottom of lakes or seas. If nothing else were deposited on the top of this clay sediment before the lake evaporated or became drained, or before the sea bottom was lifted up and became dry land, the material would retain the soft plastic condition that many of our surface clays show.

Clays may, however, originate in another manner, viz.: by the decomposition of feldspathic rock *in situ*. The feldspar alters to the mineral kaolin, which is found in variable amounts in all clays. Such clays are known as residual clays, and so far as we know do not exist in any quantity in Michigan.* Very often, the clay, when deposited in the sea, becomes covered by many feet of other sediments of a different nature, and by the weight of these overlying beds it is pressed and consolidated into quite a firm mass. When this consolidation has gone sufficiently far to form a rock-like mass (using the term rock in a popular sense) of the material, we speak of it as shale. (That pressure alone will consolidate clay particles is seen when bricks are molded by the dry clay process.)

Sometimes the firmness and hardness of the shale is increased by mineral-bearing waters filtering through the mass and cementing more or less of it together.

Shale thus originates by the consolidation of clay under pressure, and, depending on the amount of pressure it has been subjected to and the amount of cementation of the particles that has taken place, we find variations from soft shales that crumble easily under the

*Kaolin is, however, found at Hersey, Wisconsin, so that it is not altogether hopeless to look for it in the Upper Peninsula.

action of the weather to hard ones so dense and brittle that they appear and ring like slate. Indeed, shale is very commonly and erroneously called slate, especially when associated with coal; slate and shale, however, are two different materials.

Shale being of sedimentary origin was laid down or deposited in layers or beds, and it splits along these layers or planes of stratification. Furthermore, when it is ground up and mixed with water, it becomes a soft, pasty mass like clay, so that shale, simply defined, is clay which has become consolidated into a hard mass by pressure. Shales are often erroneously called slate, especially when they occur in association with coal. Slate, however, possesses no plasticity. It is a rock that has been formed from shale under the action of heat and pressure. These two agents have obliterated the original layers of stratification so that it no longer splits along them, but on the other hand a new direction of splitting has been produced, parallel to which the slate splits evenly and readily. But what is even more important is that, if the slate be ground up and mixed with water, it does not form a pasty, plastic mass like clay.

We can say in general that shales occur in those regions where the rocks lie flat or nearly so, while slate is found where the rocks have been disturbed, tilted and folded. Thus the iron bearing formations of the Upper Peninsula yield slate, while the sedimentary rocks of the Lower Peninsula carry an abundance of shale. Aside from their difference in hardness, clay and shale are practically alike in their properties, so that in this report the word shale could, in every instance, be substituted for clay without destroying the truth.

§ 2. Physical properties.

The properties of clay or shale can be divided into two classes, viz.: physical and chemical. The former are more important and have a greater practical bearing than the latter, except where the material is to be used for making Portland cement.

The most important physical properties are: slaking; plasticity; behavior under heat; shrinkage in drying and burning; color; and tensile strength.

§ 3. Slaking.

If a bed of shale is opened up, it at first appears hard and fresh, but after a while it begins to flake off in large and small pieces which either lie on the surface or fall to the base of the cliff, and these fragments continue to subdivide until the mass is broken down or slaked to clay.

If the shale crops out on a flat surface, we shall find the clay on top, and as we pass downwards a mixture of clay and partially slaked shale fragments is met with, and this mixture in turn grades into the fresh, unslaked or unweathered shale. Clays even when fresh will commonly slake rapidly in water.

Nature will often produce a far more plastic mass by weathering than could be produced by grinding the fresh material. Indeed, these weathered shale beds are often extensively employed in the manufacture of clay products. At East Jordan, for example, the material used for making brick is simply the weathered outcrop of a shale bed, and a similar material is utilized at the Coldwater cement works.

The paving brick works at Saginaw, however, mine the fresh shale and render it plastic by grinding and mixing with water.

Now, it stands to reason that the denser and more firmly cemented the shale mass is the less easily will it slake under the action of the weather, and such a shale would also be harder to grind, that is it will take longer grinding to break it up thoroughly. We therefore see that the condition of a weathered outcrop is a certain index to the way in which the shale will act in the grinding machines, it being more desirable, of course, to have a material that comminutes readily.

§ 4. Plasticity.

This we can define as the property which shale or clay possesses of forming a plastic mass when mixed with water, thus permitting it to be molded into any desired shape, which it retains when dry. It is hard to realize what an important character this really is, for without it we could do but little with the material.

Clays vary from those in which the plasticity is low to those in which it is very strong. The former are said to be lean, the latter fat or strong.

The very plastic clays and shales, other things being equal, are best adapted for making stoneware and sewer pipe and terra cotta; those of moderate plasticity find their application in the manufacture of paving brick, while the lean ones are used mostly for dry pressed brick and common brick.

If a shale is lean its plasticity can be increased by the admixture of a more plastic one; or, if, on the other hand, it is too fat, it can be tempered by the addition of sand. Sand is a powerful destroyer of plasticity, but it should also be borne in mind that the more sand

that is added the greater will be the porosity of the product. Manufacturers of common brick unfortunately have a tendency very often to add too much sand to their clay, because it makes it so much easier to work. The subject of plasticity will again be referred to under shrinkage.

§ 5. Behavior under heat.

When shale is heated up to a temperature of redness or above, depending on the refractory quality of the material, a hardening of the mass takes place, owing to the softening of the particles under the action of the heat, the result of this being that they stick together and make the product when cold as "hard as a rock." It is this property of hardening under fire that makes clay products so resistant and durable.

All clays and shales do not, however, act alike when heated. Some soften very rapidly when burned; others very slowly. Some soften at a very low temperature and are consequently said to be easily fusible; others do not soften until burned to a very high temperature and are called refractory.

A clay may fairly be classed as refractory which softens only at a temperature of 2700° F. (cone 18), though the exact limit depends upon the use to which the fire brick made of it is to be put.

Fire clays are refractory and brick clays are usually easily fusible.

When clay is put into a kiln or furnace and burned, the first signs of fusion are a softening of the particles. If the clay be now cooled, it will be a solid mass, and hard enough to cause difficulty in scratching it with a knife. It has been heated to a condition of incipient fusion. If the same piece is heated still higher, the particles soften so much that they are able to adjust themselves better and to pack to a dense, impervious mass, and when cool the individual grains will no longer be recognizable. This is the condition of vitrification, and all stoneware, paving brick and sewer pipe makers try to vitrify their wares.

If the piece of clay is once more put into the fire and heated to a higher temperature than before, the clay will finally become so soft as to cause the mass to run or become viscous.

This is known as the condition of viscosity. Now, the practical bearing of all this is that, in burning a kiln of ware to vitrification, it is impossible to bring the temperature just up to that point and then stop it; on the contrary, the heat is apt to go a little beyond before it can be stopped. If the shale passes rapidly from the condition of vitrification to viscosity, then there is danger of melting

the contents of the kiln in attempting to vitrify them. But if the two points mentioned are some distance apart, then there is not so much danger in slightly overstepping the point of vitrification.

To safely vitrify a clay, the points of vitrification and viscosity should be at least 125° Fahrenheit apart and preferably 200°. In clays containing a high percentage of lime, they are not over 50° apart, and hence such clays are not adapted to making vitrified wares. (See "Lime" under chemical properties.)

§ 6. Shrinkage.

All the clays or shales when mixed with water, molded and then set aside to dry shrink a variable amount as the water evaporates. This is known as the air shrinkage, and the more plastic the material the greater it is, while the leaner or more sandy the shale the less will be the air shrinkage.

A low shrinkage is more desirable for the reason that there is less danger of the ware warping or cracking in drying. When the ware is burned an additional diminution in volume takes place, which is known as the fire shrinkage, and for the same reasons this should be as low as possible. Most shales have a total shrinkage in drying and burning of from 12 to 15 per cent. Knowing the effect of sand on the shrinkage, it is possible to reduce it materially.

§ 7. Color.

Here we have two kinds to deal with, viz.: the color of the unburned or green clay, and that of the burned material.

Color of the Unburned Shale.—Many persons call a shale associated with coal a fire clay, simply because it is gray or reddish in color, and, while it is true that many fire clays are of this shade, still a large number of fusible ones show the same color, so that this cannot be used as a guide in determining the qualities of shale. Few deposits are wanting in organic matter, such as plant tissue, which is sometimes scattered through the shale in a very finely divided condition, coloring it gray, brown or black. When the shale is burned the organic matter simply burns off. Iron oxide is the second powerful coloring agent, and, depending on the chemical condition in which it exists in the shale, the color of the latter may be red, yellow, brown or even gray. The iron coloration may often be masked though, by the presence of much organic matter. The various states of combination, in which iron is found in the shale will be mentioned under chemical properties.

Color of Burned Clay.—This is most commonly red, owing to the presence of iron oxide in the clay, and provided the combustion of

the fire within the kiln is complete. If, however, there is not enough air admitted to permit complete combustion then the iron oxide is reduced to a lower condition of oxidation and the color will be bluish black instead of red. The same color will be produced where the clay is burned to viscosity, examples of this being bricks which have been melted in the arches of a kiln.

Shales with only 2 to 3 per cent iron oxide burn buff, while those with 4 or more per cent burn red.

A buff or cream color is also produced if the clay contains much carbonate of lime, say three times as much lime as iron, and this is what causes many of the Michigan brick clays to burn a cream color.

Magnesia exerts the same coloring effect on the burned ware as lime, and alkalies tend to turn the iron red into a brown. Silica has no effect on the color in burning. See also § 9.

§ 8. Tensile strength.

By this is meant the resistance shewn by air dried briquettes when pulled apart in a testing machine. Expressed in pounds per sq. in. it varies from 50 to 75 in many brick clays to 200 or more in very plastic pottery clays. It indicates the degree to which the clay particles will hold together and resist tearing in drying or molding.

§ 9. Chemical properties.

This includes those which are due to the chemical character or composition of the material. An analysis of pure clay would show only three ingredients, viz.: silica, alumina, and chemically combined water. Such a clay is, however, an extreme rarity, so that, in addition to the above, we usually find variable amounts of ferric oxide, lime, magnesia, and alkalies, and it can be said in general that the purer the clay the lower the percentage of the last mentioned substances. Since we speak of them as impurities, it suggests that some of them may be undesirable constituents of the clay or shale, and such is at times the case, for all of them affect some of its properties. Some influence the color, others the shrinkage, while all exert more or less effect on the fusibility of the material, the influences in each case increasing usually with the amount of the impurity which the shale contains. We can perhaps tabulate the above statements by giving in the following lines first the name of the property and after it the substances which affect it:

Fusibility: Silica, ferric oxide, lime, magnesia, alkalies.

Color: Ferric oxide, lime, magnesia, alumina.

Shrinkage: Silica, alumina, water.

On comparing these properties with those mentioned or enumerated in the first paper, it will be seen that there remain some which the chemical composition does not seem to affect, and brings up the question: What can we learn about a clay from its chemical analysis?

As we shall see below, we can learn much, and yet at the same time it is not safe to attach too much importance to this point, for two clays may agree very closely in their chemical composition, and yet be totally unlike physically.*

It is commonly the custom to divide the impurities of clay into fluxing and non-fluxing ones, but this is true only in a relative sense, for nearly all of them act as fluxes if present in sufficient quantity, and if the clay be heated to a sufficiently high temperature, but at the same time these latter tend to increase the refractoriness of the clay up to a certain point.

Those impurities, which exert a fluxing action at low or medium temperatures, include the alkalies, ferric oxide, lime and magnesia, and their effectiveness so far as we know is in the order given above.

We could therefore have two clays with the same physical properties and the same total percentage of fusible impurities and yet the one might be more fusible than the other on account of having a larger percentage of the more active fluxes in its composition. For some purposes a low percentage of fluxes is desirable, while for other purposes a higher amount is required.

§ 10. Alkalies.

These are commonly potash and soda, and are to be found in almost every clay, varying in total quantity from a trace up to nine or ten per cent. They are often present as a constituent of undecomposed feldspar grains, which the shale may contain, or in some cases the potash may come from mica, whose tiny glistening scales are easily discernible when present. Alkalies are usually present in the form of feldspar (which is a complex silicate), and, on account of their fluxing properties, are frequently of an advantage, as they serve in burning to bind the particles together in a dense, hard body, and to permit the ware being burned at a lower temperature. So far as is known the alkalies exert little influence on the color of the burned ware.

If present as sulphates or chlorides they are soluble in water and may be brought to the surface in drying, where they are left by the

*See an article by the writer on "the Ultimate and the Rational Analysis of Clays and their relative advantages." Trans. Am. Inst. of Mining Engineers, 1898, p. 1.

water evaporating from the brick and form an unsightly white coating. This can be prevented.

Efflorescence on Bricks.

Many bricks either in drying or after burning become covered by a whitish coating, which is due to the presence of soluble mineral salts, especially sulphates, which are brought to the surface by evaporating moisture and deposited there.

A very small amount of these salts, say .1% is sufficient to cause an incrustation, and yet they need not be feared if the clay is properly treated, which consists in the addition of some barium compound to the clay, and this reacting with the injurious ingredients renders them insoluble. Either barium chloride or barium carbonate may be added to the clay for this purpose, thus for example:



The barium carbonate being insoluble in water must be added to the clay in a very finely divided condition, and be mixed with it as thoroughly as possible. We may give an example.

If, for instance, the clay contained .1% sulphate of lime, this would mean that one pound contained .4 of a gram, and theoretically every gram of sulphate of lime needs 1.45 grams of barium carbonate to render it insoluble; therefore theoretically a pound of clay would require .6 of a gram of barium carbonate, or for safety 6 or 7 grams should be used for every pound of clay. This would be about 100 lbs. for every thousand bricks, based on the supposition that every green brick weighs 6 or 7 pounds. With barium carbonate at 2½¢ per pound this would be \$2.50 per 1,000 brick. If barium chloride were used, it is much cheaper and costs only about 32¢ per 1000 brick, for the reaction is quicker and less material is required.

§ 11. Iron oxide.

Aside from being a flux, iron oxide is also the great natural coloring agent of clays in both their raw and burned conditions. There are many different mineral compounds which may serve as the source of iron oxide in shale, and of these the most common are the silicate minerals, mica and hornblende; the oxides, limonite, hematite and magnetite; the sulphide, pyrite and marcasite and the carbonate of iron, siderite. No matter what the original composition of the mineral, the decomposition of it usually sets the iron

free in the form of the hydrated iron oxide or limonite, which tends to color the clay in various shades of red and yellow. In burning this changes to hematite. Aside from the mica, the only other mineral which is apt to be present in grains sufficiently large to be recognized by the naked eye, is pyrite, and this occurs in the form of glittering yellow metallic particles, which are often of cubical shape, many of these grains being sometimes cemented together in the form of large masses, which are commonly known as "sulphur balls." The latter would tend to do much damage if allowed to remain in the shale, but owing to their size are easily extracted. If the finely disseminated pyrite remained in the clay it would be found after burning that the clay was dotted with fused spots of silicate of iron. Many of the first speckled, "Pompeian," brick so extensively used at the present time were made in this manner. The pyrite is a strong flux.

These should not be mistaken with carbonate of iron concretions commonly found in shale banks, and known as clay iron stone, or kidney ore, and sometimes erroneously called sulphur. They do not show any metallic particles unless grains of pyrite happen to be enclosed in them. The shales at Flushing, Grand Ledge, and Quincy, etc., contain many concretions of carbonate of iron.

When a shale is exposed to an oxidizing fire in burning, the iron invariably tends to color the material red, and the depth of this color increases with the amount of iron present. If, however, the shale is exposed to a reducing action in burning, which is the case when an insufficient quantity of air enters the kiln, then the color instead of being red will be a bluish black. The same color is also produced if even in an oxidizing fire the shale is carried to a condition of viscosity, in which state a dissociation of the iron compound takes place, the ferric oxide being reduced to the ferrous condition.

Both ferric and ferrous oxide exert distinct coloring effects on the raw clays, so that the latter may be yellow, blue, brown, red or grey in color, depending upon the relative amount of ferrous and ferric salts present.

The amount of ferric oxide permissible or desirable in a shale depends upon the use to which it is to be put. Thus kaolins, which are to be utilized for making china, should have under one per cent if possible, while brick shales or pottery clays, on the other hand, should have four or five per cent of the same material in order to

produce the good red coloration. A large excess of iron oxide also tends to cause blistering in burning.

The iron coloration may often be bleached out owing to the presence of lime, as will be mentioned further on.

§ 12. Lime.

There are scarcely any shales which do not contain some lime. The chemical combination in which it is present has much to do with its effect on the behavior of the shales. Thus it may occur as a silicate, when present in some species of feldspar, or again it may be found in the shale as a simple carbonate, represented by the mineral calcite, or as a double carbonate of lime and magnesia when the mineral dolomite is present. Thirdly, it may be found in the shale as a sulphate, namely the mineral gypsum. The latter is often known by its small transparent crystals, whose surfaces have a pearly lustre. The presence of carbonate of lime can be detected by the effervescence produced when a drop of muriatic acid is put on the shale, and dolomite shows itself by acting similarly when hot acid is dropped on the rock.

When the lime is present as a silicate, it is useful as a flux, but in this condition it exerts no coloring action on the shale in burning. Carbonate of lime is extremely common in many shales, which have been derived from limestone areas, as in the State of Michigan, and it is never lacking in those beds of brick clay which are found around the borders of the Lower Peninsula, as at Detroit, Benton Harbor and Forestville, or even in many of the Upper Peninsula beds. Carbonate of lime if present in the form of lumps or pebbles is very injurious, and should be removed by screening or washing, for the reason that in burning it is reduced to quick lime, which if the brick is not vitrified absorbs moisture from the atmosphere, slakes, swells and bursts the product. Finely divided lime, however, if not present in too large quantities may be harmless, and shales containing 15 or 20 per cent of lime carbonate in this condition can be used for the manufacture of common brick or earthen ware, or in fact any products which do not have to be burned to a condition of vitrification.

Lime like iron and alkalies is also a powerful flux and tends to lower the fusibility of the shale to a marked extent; furthermore it tends to bring the points of incipient fusion and viscosity of the clay together so close that shales which contain a large amount of carbonate of lime can not be burned to a condition of vitrification without danger of fusing.

The effect of lime as a coloring agent is that, if iron oxide is present, the lime unites with it and the silica, and alumina of the shale giving a complex silicate, and coloring the brick buff or cream instead of red. This is especially effective when the ratio of lime to iron is not less than three to one.

In addition to this, lime also exerts a powerful influence on the shrinkage of shale, those which are highly calcareous showing a lower shrinkage in burning than those with a low lime percentage.

§ 13. Magnesia.

This element rarely occurs in either shales or clays in the same amount as lime, and indeed it rarely exceeds two per cent. But curiously enough the shales and the clays at many localities in Michigan often seem to contain as much magnesia as lime.*

Magnesia may be derived from the same class of compounds as lime, and, so far as known, the action of it on the clay in burning is exactly the same.

§ 14. Silica.

Chemical analysis distinguishes two classes of silica, first, that combined with alumina in kaolin, and, second, sand. The latter includes both quartz and silica present in feldspar or mica.

Free silica or quartz is present in all shales, and varies in amount from a fraction of a per cent to about 20 or even 50 per cent. Its most important effects are that it tends to lessen the plasticity, diminish the tensile strength, and also lower the shrinkage of the material, both in drying and in burning. Indeed, if silica is present in a very large amount and grains of large size, it may even cause the shale to expand in burning.

Silica, namely quartz, tends to increase the refractoriness of a clay up to a certain point, namely about 2800° F. Beyond that point, however, an increase in the amount of silica tends to increase the fusibility of the clay up to a certain point, after which the refractoriness again rises. This is a question which has a practical bearing, however, only in connection with the highest grades of fire bricks.

§ 15. Titanium.

While this is widespread in many clays in the form of the mineral rutile or ilmenite, at the same time it is present in such small quantities that its effect need not usually be considered. Its action is somewhat similar to that of silica.

*Prof. C. A. Davis has found some shales from the Grand Traverse region to be very high in magnesia. The irregularity in the amount of magnesia in the calcareous surface clays is well shown in the two analyses from Ionia.

§ 16. Organic matter.

This substance is found in many different shales and usually makes its presence known by the dark gray or black color which it imparts to the material. It generally consists of finely divided pieces of plant tissue, or large pieces of stems and leaves, which have settled in the shale during its deposition.

The color exhibited by clays carrying organic matter is no indication of the color they will have when they are burned, for a clay which is jet black might contain no iron, and consequently would burn with a white color, as the plant tissue passes off at a bright red heat. On the other hand, a clay might contain an appreciable per cent of iron, whose presence would be masked by the presence of organic matter, and consequently the clay would burn red.

When found in a very finely divided condition, organic matter tends to increase the plasticity of the clay, unless there is a large amount of sand present, and furthermore in the weathering of shales organic matter by its oxidation and consequent evolution of carbonic acid gas helps to break up the material and render it more plastic.

§ 17. Water.

All shales and clays contain two kinds of water, viz.: hygroscopic water, or moisture and chemically combined water.

Moisture.—Shales contain from 30 to 40 per cent of moisture, when freshly taken from the bank, and in air drying most of this is expelled, the clay shrinking at the same time. The amount of water that an air dried clay needs in order to develop an easily workable mass varies from 12 to 20 per cent in lean ones, and from 25 to 35 in fat ones. The more plastic the shale the greater the quantity of water required.

Combined water.—It may be said roughly that the amount of combined water in shales is usually about one-third of the amount of alumina, although if the clay contains much limonite it would be much greater than this. Combined water is driven off at a low red heat, and the only effect of it is that when this takes place the shale suffers additional loss in volume or shrinks, otherwise combined water has little or no effect. It is a curious fact, however, that while the amount of combined water does not seem to stand in any close relation to the plasticity of a clay, nevertheless when once driven off the clay can never again be rendered plastic by the addition of water. The shrinkage that does take place when combined water is driven off will vary from two to twelve per cent.

§ 18. Minerals in clay.

There is really no limit to the number of minerals that may be found in clay, when we consider that it has originated by the breaking down of many other rocks. Unfortunately, however, very little systematic work has been done in this line so that the number actually identified is few.

All that it is desired to do here is to simply call attention to a few of the commoner species that are often noticeable in clay, especially with the naked eye or a hand lens.

Quartz is perhaps the most abundant. It is present in nearly all clays, in the form of tiny angular or rounded grains. In washing the clay they usually settle out quickly, and are included under the term of sand, which however may include other gritty mineral fragments coarse enough to be felt between the teeth. The chief purpose which quartz serves is to dilute the shrinkage. Its presence can be determined by the fact that it will scratch glass. In some clays quartz forms large lumps and is then spoken of as flint or chert.

Feldspar is a common constituent of many clays; so are garnet, hornblende and pyroxene. They are all complex silicates, which fuse at a much lower temperature than quartz. Up to their fusing point they act like quartz in retarding the shrinkage of the clay, but above that they probably increase it.

They rarely occur in clay in sufficiently large grains to be recognized except by the aid of high power lenses.

Mica is a very common ingredient of clays, and while it is a complex silicate like the preceding, still it is so different in its effect as to necessitate giving it separate mention.

Its form is that of shining scales, which are usually distinguishable on account of their brilliant surfaces, even though very small.

There are two common types of mica, the one known as muscovite or white mica, and the other known as biotite or dark mica. The former contains but little iron oxide, and weathers very slowly, while the latter has much and weathers rapidly. Hence it is the former usually that is found in clay. The effect of mica is to increase the refractoriness of clay and decrease its plasticity, and it is often noticeable that the mica scales retain their lustre, and refrain from fluxing with other elements of the clay, even when heated to bright redness.

Gypsum, the sulphate of lime, is abundant in many shales and clays, and while it, like mica, is often present in the form of tiny, shiny, scales or plates, still their effect on the clay is different.

They can be distinguished from mica in several ways. First, their lustre is pearly; second, they are soft enough to be scratched with the finger nail, while it takes a knife to scratch mica; third, at a temperature of 300° F. (much below redness) they lose their lustre and change to a white, powdery mass.

In burning they serve as a flux, and furthermore if present in the clay in large quantity, the gypsum dissociates at redness, allowing the escape of sulphuric acid gas, which, if abundant, may cause blistering of the ware.

Calcite or carbonate of lime, is often found in clays either as tiny grains, large lumps and pebbles, or as an ingredient of the concretions often seen and sometimes called "clay dogs."

It serves as a flux and otherwise as explained under the chemistry of clays. If in the form of pebbles or concretions it should be either ground up in the clay or removed by screening, as underburned lumps are sure to slake and burst the brick.

Pyrite is still another constituent that often impresses itself on our notice, by its occurrence either in the form of yellow, metallic grains or larger lumps of concretionary nature. It is often spoken of by the clay workers as "sulphur" or "sulphur balls."

It is an undesirable constituent, and should be removed when possible; it is apt to be found in many fire clays and shales.

Limonite should be mentioned as absent from very few clays, but it is present commonly as a film coating the other mineral grains. It is an important coloring agent in burning, and in the raw condition colors the clay yellow or brown.

Many other species might be mentioned, but they are all microscopic and only determinable by careful study.

Siderite or iron carbonate is a common cause of concretions in clay, and especially shale. It should be treated in a similar manner to lime carbonate concretions although in burning it simply acts as a coloring agent and flux.

CHAPTER II.

USES OF CLAY AND SHALE.

§ 1. Clay products.

This represents by far the most important use to which shale is put at the present time, and for its successful application depends on the two properties mentioned in the previous chapter, viz.: plasticity and hardening when burned. The various chemical and physical properties of shale which have been described in the preceding papers bear chiefly on the use of shale for this purpose.

For the manufacture of all of these clay products the shale must be plastic, but aside from this the characters to be considered for any particular grade of products are not always the same. The necessary qualities may be summed up briefly therefore as follows:

§ 2. Common brick.

A sufficient amount of iron oxide to give the brick a good red color is desirable but not absolutely necessary, otherwise we should be excluding the use of calcareous shales, which are sometimes employed, from a matter of necessity rather than choice. There should be enough fluxes in the shale to make it burn to a hard product at a comparatively low temperature, giving a brick whose density should not allow over 15% absorption.

§ 3. Front brick.

The same characters are called for as in the case of common brick, but the color after burning is of prime importance, it being necessary that the shade, whatever it is, should be uniform. A dense brick is desirable, and the shrinkage should be low enough to prevent warping or cracking in burning. These two points are also influenced by the proper manipulation of the clay. Furthermore, soluble salts must always be guarded against, for they produce a bad discoloration on the surface of the ware. If their presence is known they can be rendered harmless by the addition of barium chloride or barium carbonate to the clay, the chemical reaction

which takes place as a result of this addition rendering them insoluble.

§ 4. Manufacture of brick.

While it is not proposed to go into a detailed discussion of the methods of manufacture, still there are a few general points which call for attention. In the manipulation of clays and their forming into brick, the different steps of the process commonly followed are:

Preparation.

Tempering.

Molding.

Drying.

Burning.

Under preparation is meant the bringing of the clay into a condition suitable for mixing with water. Soft plastic clays require little preparation, but shales have to be ground before they can be made into a plastic mass.

The increase or development of plastic qualities is in many places effected by simple grinding, at others by weathering, the raw material being allowed to remain in the open air exposed to the elements for several months, or even a year. This method comes into use when clays are employed for pressed brick, or to a still greater extent when they are employed for refractory wares.

The tempering involves the mixing up of the clay or shale with water, in order to bring it into a mass of the proper consistency for molding. Sometimes several clays are mixed together, or sand has to be mixed in if the clay is highly plastic and shrinks too much. At any rate, too much stress cannot be laid on the importance of thorough tempering, a point whose value increases with the grade of the ware.

The molding may be done in several different ways, depending on the clay and the quality or nature of product to be produced.

The methods are characterized as:

1. Soft mud, the clay being molded soft.
2. Stiff mud, the clay being molded stiff.
3. Dry press, in which the clay is forced into the molds as dry powder.

Soft mud bricks are thoroughly homogeneous and when properly burned seldom disintegrate under the action of frost. They represent the method commonly employed for common brick. Paving

bricks are in rare instances made by this method, the objection to its use for this class of products being comparatively low capacity of output.

The stiff mud process is one of high capacity, and is usually employed for making pavers. It is not applicable to very plastic or very lean clays.

The one objection to its use is that it develops a spiral structure in the bricks, but if properly burned, and sometimes repressed, the effect of this feature is less felt.

The dry press process produces a smooth face and sharp edged brick at one operation, and consequently is especially adapted for the manufacture of face brick.



Fig. 1. Molding bricks on auger machine with triple die.

The drying is carried on either out of doors or under cover, and in the latter case artificial heat is often made use of. Still it is not always safe to hurry this step of the process of manufacture for many clays will not stand it.

The same care has to be taken in the burning, for a large portion of the success of clay working, depends on its proper manipulation. Some clays require slow heating, others can be burned quickly.

The higher the grade of product, the greater the care which has to be exercised. Better wares are also burned in more complicated forms of kilns, for in these the heat can be regulated with greater precision. Even with the best types of kilns, and the utmost care, the burned ware has at times to be sorted.

§ 5. Paving brick.

The production of these calls for a clay or shale that will not only keep its shape in burning but also yield a vitrified or impervious product. To produce the latter in large quantities at a time, it is necessary that the points of incipient fusion and viscosity of the shale should be separated by at least 250° Fahr., and preferably 400°. The product should have little or no absorption, and should also withstand abrasion, this being even of more importance than the crushing strength of the brick, although the latter should not be lost sight of, and be at least 7,000 or 8,000 pounds per square inch.

§ 6. Terra cotta.

The same requirements have to be considered as in the case of front brick, but they must be complied with even more strictly. The necessary plasticity to permit the molding of intricate designs is also of the highest importance.

§ 7. Pottery.

Here plasticity has to be considered, and should be made high in order to permit the turning or molding of the ware. Color is sometimes of importance, and, for stoneware, the shale must burn to a vitrified body. So far as the writer is aware, shale has never been used for the manufacture of white ware, for the reason that shale being of sedimentary origin it usually has too much iron oxide in its composition to permit its burning to a white body.

§ 8. Firebrick.

These are very frequently manufactured from shale. The great element to be considered in this case is ability of the ware to withstand high temperatures. This calls for a low percentage of fluxes in the raw material. Fineness of grain always plays an important roll. Coarse-grained shales withstand high temperature best, while fine-grained ones are better adapted to resist the corrosive action of molten materials.

It is frequently found that a mixture of shales often yields much better results than when one alone is used.

§ 9. Portland cement.

In the manufacture of Portland cement a mixture of shale and marl is usually taken, the two being mixed in such proportions as to give a mixture of the proper chemical composition, the physical properties of the material being of minor importance. The three essential elements of such cement are silica, alumina and lime, the first two of which are supplied by the shale and the latter by the marl or limestone. The best results are obtained from a mixture in which the lime percentage is equal to 2.8 times the silica plus 1.1 times the alumina.*

§ 10. Mineral paint.

Shale to be thus employed is usually ground up and mixed with oil. Two characters enter into the consideration of its applicability for this purpose. First, the amount of oil required to mix with a given quantity of shale, and, second, the color of the raw material, which is influenced by the amount of iron oxide and organic matter in the raw material. The paint is usually some kind of ochreous paint.

§ 11. Road material.

In many localities excellent roads are produced by the use of shale, the varieties yielding the best results being those of a somewhat hard and silicious nature. Shales which are soft and low in silica tend to crumble rather rapidly to dust and produce a greater amount of mud in wet weather.

When burned the results are much better. The black shales and sulphurous coal waste from coal mines and the broken waste from brickyards are material which may well be more largely used. In Missouri a black silty clay mud called gumbo is largely burned for road metal and railroad ballast.

§ 12. Slip clays.

These are clays of a highly fusible quality, which are used to give a brilliant color and finish to stoneware. The clay from Albany, N. Y., is the best known, and normally gives a dark color. A slip clay must be fusible thoroughly at a temperature at which the body of the stoneware will not soften. The Rowley slip, the Northern

*A shale or clay to be suitable for use in cement manufacture should be free from grit, that it may not be expensive to grind and mix, and should be free from carbonates, i. e., should not effervesce with acids. This is not theoretically requisite, but practically it is found that calcareous shales are likely to prove irregular in composition, and introduce uncertain quantities of magnesia. The glacial clays are rarely suitable, being too calcareous. The shales of the coal measures when not gritty appear more suitable. But of particular value are the shales of the Coldwater (Cuyahoga) series. See Ch. III, § 7, pp 41 to 44.

Michigan slip described below, burns to a yellowish green glass, (Analyses Nos. 32 and 33), and so does the Harrietta clay (Analysis No. 42). Orton gives us an average composition for slip clays: 31% clay base, 39% sand, 21% fluxes, 9% water and carbonic acid, and it will be seen that very many of the Michigan surface clays ought to make good slip clays.

CHAPTER III.

TESTS.

§ 1. Introduction.

Michigan contains two types of clay materials, viz.: clays proper and shales. The former are mostly surface deposits, while the latter are found both outcropping at the surface and are also encountered in sinking shafts for the purpose of mining coal or other mineral products.

The present report does not aim to be an exhaustive one on these materials so far as Michigan is concerned, but is intended to serve the purpose of pointing out in a general way what the properties of these materials as they occur within the state are, so that some judgment can be formed as to what they are probably good for.

A state can have valuable clay resources, without containing any deposits of the highest grades of clay such as kaolin. Michigan so far as is known does not contain any kaolin, and although there are rumors of its occurrence in the upper Peninsula, still careful inquiries in that region failed to develop the presence of any.

None of the shales so far as examined are refractory in the true sense although many of them are spoken of as fire clays, especially when they underlie the coal. Many of them however have developed qualities which should make them suited for other types of ware of importance.

In collecting the samples for this work the plan followed was to visit a number of localities where extended and typical outcrops could be found of the different geological clay bearing formations.

While a great number of samples were collected, about thirty-two of them in all were subjected to a physical test, and in some cases a chemical analysis was also carried out. The analyses were made by Mr. A. N. Clark.

§ 2. Methods of testing.

The physical tests carried out on the different samples, were determination of the slaking properties, plasticity, tensile strength,

amount of water required to mix up the clay or shale, points of incipient fusion, vitrification and viscosity, color when burned, shrinkage in drying and burning, and the percentage of soluble salts contained in the clay or shale.

The object of such tests is a double one. It gives us in the first place a clue or several clues to the uses of the clay, it serves to give information to a manufacturer who is searching for a particular clay or shale, and thirdly it may be used as a basis of comparison with other materials which are being used.

Pyrometric cones.

In many works the completion of the firing is judged by trial pieces placed in the kiln, these being withdrawn singly from time to time, and their condition examined.

A surer method and one gaining favor in this country, is by the use of Seger's Pyramids.

These consist of different mixtures of kaolin and fluxes, which are compounded so that there shall be a constant difference between their fusing points. Seger's series were numbered from 1 to 20, and the difference between their fusing points is 36° F. A later series, introduced by Cramer, runs from 01 to 022 with a difference of 54° F. between their fusing points. The higher numbers of the cones have also been extended up to 36.

These pyramids have been recently recalibrated, and therefore the fusing points and composition of the different numbers are given herewith, being taken from the recently issued circular of the Thonindustrie Laboratorium, in Berlin, where these cones were first made.

FUSION TEMPERATURES BASED UPON RECENT RECALIBRATIONS FOR SEGER'S PYRAMIDS:

Number of cone.	Composition.		Fusion point.	
			Cent.	Fahr.
022.....	0.5 Na ₂ O	2 SiO ₂	590	1094
	0.5 Pb O	1 B ₂ O ₃		
021.....	0.5 Na ₂ O	2.2 SiO ₂	620	1148
	0.5 Pb O	1 B ₂ O ₃		
020.....	0.5 Na ₂ O	2.4 SiO ₂	650	1202
	0.5 Pb O	1 B ₂ O ₃		
019.....	0.5 Na ₂ O	2.6 SiO ₂	680	1256
	0.5 Pb O	1 B ₂ O ₃		
018. Dull red heat.....	0.5 Na ₂ O	2.8 SiO ₂	710	1310
	0.5 Pb O	1 B ₂ O ₃		
017.....	0.5 Na ₂ O	3.0 SiO ₂	740	1364
	0.5 Pb O	1 B ₂ O ₃		
016.....	0.5 Na ₂ O	3.1 SiO ₂	770	1418
	0.5 Pb O	1 B ₂ O ₃		
015.....	0.5 Na ₂ O	3.2 SiO ₂	800	1472
	0.5 Pb O	1 B ₂ O ₃		
014.....	0.5 Na ₂ O	3.3 SiO ₂	830	1526
	0.5 Pb O	1 B ₂ O ₃		
013.....	0.5 Na ₂ O	3.4 SiO ₂	860	1580
	0.5 Pb O	1 B ₂ O ₃		
		0.7 Al ₂ O ₃		

Number of cone.		Composition.			Fusion point.	
					Cent.	Fahr.
012.	Cherry red heat.....	0.5 Na ₂ O 0.5 PbO	0.75 Al ₂ O ₃	3.5 SiO ₂ 1 B ₂ O ₃	890	1634
011.	.....	0.5 Na ₂ O 0.5 PbO	0.8 Al ₂ O ₃	3.6 SiO ₂ 1 B ₂ O ₃	920	1688
010.	.....	0.3 K ₂ O 0.7 CaO	0.2 Fe ₂ O ₃ 0.3 Al ₂ O ₃	3.5 SiO ₂ 0.5 B ₂ O ₃	950	1742
09.	.....	0.3 K ₂ O 0.7 CaO	0.2 Fe ₂ O ₃ 0.3 Al ₂ O ₃	3.55 SiO ₂ 0.45 B ₂ O ₃	970	1778
08.	.....	0.3 K ₂ O 0.7 CaO	0.2 Fe ₂ O ₃ 0.3 Al ₂ O ₃	3.60 SiO ₂ 0.40 B ₂ O ₃	990	1814
07.	} Clear cherry red heat.....	0.3 K ₂ O	0.2 Fe ₂ O ₃	3.65 SiO ₂	1010	1850
06.		0.7 CaO	0.2 Al ₂ O ₃	0.35 B ₂ O ₃		
		0.3 K ₂ O	0.2 Fe ₂ O ₃	3.70 SiO ₂	1030	1886
		0.7 CaO	0.3 Al ₂ O ₃	0.30 B ₂ O ₃		
05.	.....	0.3 K ₂ O 0.7 CaO	0.2 Fe ₂ O ₃ 0.3 Al ₂ O ₃	3.75 SiO ₂ 0.25 B ₂ O ₃	1050	1922
04.	.....	0.3 K ₂ O 0.7 CaO	0.2 Fe ₂ O ₃ 0.3 Al ₂ O ₃	3.80 SiO ₂ 0.20 B ₂ O ₃	1070	1958
03.	.....	0.3 K ₂ O 0.7 CaO	0.2 Fe ₂ O ₃ 0.3 Al ₂ O ₃	3.85 SiO ₂ 0.15 B ₂ O ₃	1090	1994
02.	.....	0.3 K ₂ O 0.7 CaO	0.2 Fe ₂ O ₃ 0.3 Al ₂ O ₃	3.9 SiO ₂ 0.1 B ₂ O ₃	1110	2030
01.	} Deep orange heat.....	0.3 K ₂ O	0.2 Fe ₂ O ₃	3.95 SiO ₂	1130	2066
		0.7 CaO	0.3 Al ₂ O ₃	0.05 B ₂ O ₃		
1.		0.3 K ₂ O	0.2 Fe ₂ O ₃	4 SiO ₂	1150	2102
		0.7 CaO	0.3 Al ₂ O ₃			
2.	} Deep orange heat.....	0.3 K ₂ O	0.2 Fe ₂ O ₃	4 SiO ₂	1170	2138
		0.7 CaO	0.4 Al ₂ O ₃			
3.		0.3 K ₂ O	0.5 Fe ₂ O ₃	4 SiO ₂	1190	2174
		0.7 CaO	0.5 Al ₂ O ₃			
4.	} Deep orange heat.....	0.3 K ₂ O	0.5 Al ₂ O ₃	4 SiO ₂	1210	2210
		0.7 CaO				
5.	.....	0.3 K ₂ O 0.7 CaO	0.6 Al ₂ O ₃	5 SiO ₂	1230	2246
6.	.....	0.3 K ₂ O 0.7 CaO	0.7 Al ₂ O ₃	6 SiO ₂	1250	2282
7.	.....	0.3 K ₂ O 0.7 CaO	0.7 Al ₂ O ₃	7 SiO ₂	1270	2318
8.	.....	0.3 K ₂ O 0.7 CaO	0.8 Al ₂ O ₃	8 SiO ₂	1290	2354
9.	White heat.....	0.3 K ₂ O 0.7 CaO	0.9 Al ₂ O ₃	9 SiO ₂	1310	2390
10.	.....	0.3 K ₂ O 0.7 CaO	1.0 Al ₂ O ₃	10 SiO ₂	1330	2426
11.	.....	0.3 K ₂ O 0.7 CaO	1.2 Al ₂ O ₃	12 SiO ₂	1350	2462
12.	.....	0.3 K ₂ O 0.7 CaO	1.4 Al ₂ O ₃	14 SiO ₂	1370	2498
13.	.....	0.3 K ₂ O 0.7 CaO	1.6 Al ₂ O ₃	16 SiO ₂	1390	2534
14.	Bright white heat.....	0.3 K ₂ O 0.7 CaO	1.8 Al ₂ O ₃	18 SiO ₂	1410	2570
15.	.....	0.3 K ₂ O 0.7 CaO	2.1 Al ₂ O ₃	21 SiO ₂	1430	2606
16.	.....	0.3 K ₂ O 0.7 CaO	2.4 Al ₂ O ₃	24 SiO ₂	1450	2642
17.	.....	0.3 K ₂ O 0.7 CaO	2.7 Al ₂ O ₃	27 SiO ₂	1470	2678
18.	.....	0.3 K ₂ O 0.7 CaO	3.1 Al ₂ O ₃	31 SiO ₂	1490	2714
19.	} Dazzling white heat.....	0.3 K ₂ O	3.5 Al ₂ O ₃	35 SiO ₂	1510	2750
		0.7 CaO				
20.		0.3 K ₂ O	3.9 Al ₂ O ₃	39 SiO ₂	1530	2786
		0.7 CaO				
21.	} Dazzling white heat.....	0.3 K ₂ O	4.4 Al ₂ O ₃	44 SiO ₂	1550	2822
		0.7 CaO				
22.		0.3 K ₂ O	4.9 Al ₂ O ₃	49 SiO ₂	1570	2858
		0.7 CaO				
23.	.....	0.3 K ₂ O 0.7 CaO	5.4 Al ₂ O ₃	54 SiO ₂	1590	2894
24.	.....	0.3 K ₂ O 0.7 CaO	6.0 Al ₂ O ₃	60 SiO ₂	1610	2930
25.	.....	0.3 K ₂ O 0.7 CaO	6.6 Al ₂ O ₃	66 SiO ₂	1630	2966
26.	.....	0 K ₂ O 0.7 CaO	7.2 Al ₂ O ₃	72 SiO ₂	1650	3002
27.	.....	0.3 K ₂ O 0.7 CaO	2.0 Al ₂ O ₃	200 SiO ₂	1670	3038
28.	.....		Al ₂ O ₃	10 SiO ₂	1690	3074
29.	.....		Al ₂ O ₃	8 SiO ₂	1710	3110
30.	.....		Al ₂ O ₃	6 SiO ₂	1730	3146
31.	.....		Al ₂ O ₃	5 SiO ₂	1750	3182
32.	.....		Al ₂ O ₃	4 SiO ₂	1770	3218
33.	.....		Al ₂ O ₃	3 SiO ₂	1790	3254
34.	.....		Al ₂ O ₃	2.5 SiO ₂	1810	3290
35.	.....		Al ₂ O ₃	2 SiO ₂	1830	3326
36.	.....		Al ₂ O ₃	2 SiO ₂	1850	3362

The theory of these pyramids is that the cone bends over as the temperature approaches its fusing point. If the heat is raised too rapidly, the cones which contain much iron swell and blister and do not bend over, so the best results are obtained by the slow softening of the cone under a gradually rising temperature. For practical purposes these cones are considered sufficiently accurate.

In actual use they are placed in the kiln at a point where they can be watched through a peep hole, but at the same time will not receive the direct touch of the flame from the fuel. It is always well to put two or more cones in the kiln, so that warning can be had not only of the approach of the desired temperature, but also of the rapidity with which the temperature is rising.

In order to determine the temperature of the kiln several cones of separated numbers are put in, as for example: .07, 1 and 5. Suppose .07 and 1 are bent over in burning, but 5 is not affected; the temperature of the kiln is therefore between 1 and 5. The next time Nos. 2, 3 and 4 are put in; 2 and 3 may be fused but 4 remains unaffected, indicating that the temperature reached the fusing point of 3. These cones can be obtained for about one cent each from Prof. E. Orton, Jr., Ohio State University, Columbus, Ohio.

§ 3. Prospecting for clays.

In searching for clays or shales a few points borne in mind may often be of value.

The first point is to find exposures of the material sought, that will give us some clue to their extent and thickness. Ravines, railroad cuttings, bluffs along the lake shore and other natural or artificial excavations are admirable aids.

Location and homogeneity play an important role. Unless a clay is valuable, or used in enormous quantities, it will not often pay to open up a bank or pit remote from lines of transportation. If the deposit consists of layers of varying character, it does not pay to work out a few good ones, and strip off the others unless the value of the raw material is appreciable.

It is true that when a single bed 4, 6 or more feet thick is covered by many feet of rock, that underground mining is sometimes employed by running in a drift along the bed, if it outcrops on a hillside, or sinking a shaft to it. Shale beds can often be worked in connection with coal seams. If a bed of clay appears favorable on its outcrop, the extension of it under the surface can be probed by boring, or the sinking of a small shaft, still few people seem to

realize the value of thoroughly determining the extent of a deposit by boring or shafting.

Another point to be remembered is that all shales do not grind up to masses of highly plastic qualities, and we may gain some ideas on this point from the manner in which they weather in the outcrop. Very plastic shales mellow down to a tough clay, while others do not exhibit these qualities, refusing to break up beyond angular particles of varying size.

Soluble salts may also occasionally make themselves noticeable by the formation of a white, powdery coating on the outcrop. This coating may be alum, carbonate of lime or gypsum.

§ 4. Geology of shale deposits.

The principal shale deposits occurring within the State are the following:

1. Coal measure shales, usually interbedded with the coal seams.
2. Michigan series of shales, associated with the gypsum beds.
3. Coldwater shales, outcropping in abundance near Coldwater and White Rock.
4. The St. Clair, Devonian or Genesee black shale. Besides these there are other beds of shale of minor importance apparently. There are considerable beds of shale in the Hamilton or Traverse and about the horizon of the Marcellus. The Hudson River group is not very shaly in its northern part, though it is so found in borings to the south.

§ 5. Coal measure shales.

The coal measure shales are, as already mentioned, usually interbedded with coal seams, and most commonly known to the coal miners of the State as "fire clays." This term is erroneous, for none of the shales have developed very refractory qualities. The term has probably arisen from the fact that in many coal mining regions the coal beds are underlain by a layer of fire clay or refractory shale, which means the same thing. It is very difficult to give even a most general description of these Carboniferous shales, for the reason that they vary so at the different mines, but the same kind is sometimes met with at several mines in succession. The types which are most distinct are perhaps the following: 1, A light gray, sandy, shaly clay, often quite hard, and called fire clay. It not unfrequently contains plant remains. This material underlies the coal at the shaft of the Standard Mining Company near Saginaw. 2, A black fine-grained, brittle shale, with dull lustre and

sometimes spoken of as cannel coal, owing to its appearance. This shale contains much bituminous matter, and would not serve well for the manufacture of clay products. 3, A dark, grayish black, fine-grained, hard, yet brittle shale, which produces appreciable plasticity when ground up and mixed with water. This is found at several mines near Saginaw and also Bay City, and is quarried at Flushing for the manufacture of paving brick. For analyses of the three types see the following pages.

Between these three types are intermediate gradations.

The following analysis shows the composition of the "fire clay" underlying the coal at the shaft of the Standard Mining Company at Saginaw:

ANALYSIS 1.

	Per cent.
Silica	55.30
Alumina	14.20
Ferric oxide	3.62
Lime carbonate .....	.30
Magnesium carbonate	2.61
Alkalies	2.15
Water and organic matter.....	21.82
Total	<u>100.00</u>
Fluxes	8.68

This shows a high percentage of organic matter, as the water does not exceed 5% probably, judging from the amount of alumina, and consequently there would probably be a considerable shrinkage in burning were it not for the high sand content. The fluxes are also too high for a fire clay, but the material may be semi-refractory.

These beds of shale at many of the coal mines are four to five feet in thickness, and there is usually an abundant supply of the material. At present it is either left in the mine or else brought to the surface and thrown on the dump, where after a while it begins to slake, first to a scaly mass and then to a powder.

At Grand Ledge the coal measure shales are utilized for the manufacture of tile and sewer pipe, as described below, and at Saginaw there is a successful paving brick plant in operation.

The regions which were visited by the writer were Owosso, Coruna, St. Charles, Verne, Saginaw, Bay City and Sebewaing. Samples were collected from those localities which appeared promising.

Owosso.

There are two coal shafts near Owosso, viz.: those of the Owosso Coal Co. (Sec. 23, T. 7 N., R. 3 E), and the Corunna Coal Co. At both of these considerable shale is extracted with the coal and brought to the surface.

At the mine of the Owosso Coal Co., the coal is underlain by a light gray and at times sandy micaceous shale called fire clay locally. On exposure to the weather for several months the material slakes to a clay. The shale at times contains concretions of pyrite or even calcareous nodules with zinc, but these could be separated in mining the material. Overlying the coal is a black brittle shale containing considerable bituminous matter, and also pyrite. Both the underlying and the overlying material are of variable thickness, viz., from 2 to 8 ft.

The black upper shale is covered by sandstone.

At the shaft of the Corunna Coal Company the underlying shale is similar to that at the Owosso shaft, but the overlying material is similar to the upper clay used at the Saginaw Clay Mfg. Co. works. At both mines the coal is about 75 feet below the surface.

A sample of the underlying material at the Owosso shaft was tested with the following results:

Owosso Under Clay. (Lab. No. 226.)

This is a gritty, gray, sandy shale, which underlies the coal bed at Owosso, and is known as the fire clay. The material varies in thickness from 3 to 5 feet, and is not as much consolidated as the shales which are found associated with the coal at many of the other mines of Michigan, for when lumps of it are thrown into water they slake down slowly into angular fragments, while the shales from other localities do not slake at all. When mixed with water it gave a paste of very low plasticity; it required but 19% of water to work it up. The raw clay showed very little pyrite, but an abundance of mica scales. It did not effervesce much showing thereby the absence of any appreciable amount of carbonate of lime. The soluble salts in it amounted to only .3%.

In burning, when heated to cone 05 the color of the clay was buff; it could still be easily scratched by the knife and the mica scales still showed their lustre, the total shrinkage being 6%; incipient fusion did not occur until the clay had been heated to cone 02 at which

point the total shrinkage was 7%, while the clay began to vitrify at between cone 4 and cone 5, with a total shrinkage of 9%, the color of the burned briquette being buff. Viscosity began at cone 9, thus showing that the material is not refractory as has been at times supposed. The iron oxide is not evenly distributed through the clay and produces fused specks.

The tensile strength of the air-dried briquettes is naturally very low owing to the coarse grain of the material, the lack of plastic particles and ranged from 35 to 40 pounds per square inch the average being 37 pounds.

Although this shale is easily accessible and can be mined in considerable quantities, it has not up to the present time been utilized to any great extent, although it has been stated that at one time portions of it were shipped to the earthenware factory at Ionia.

It is hardly plastic enough for paving brick manufacture, but the best results could probably be obtained by mixing it with a more plastic clay.

St. Charles.

The mine of the J. H. Somers Coal Co., is located close to the Michigan Central R. R. station. The coal bed is 185 feet below the surface and is interbedded in shale. The overlying shale is rather brittle and gritty, but on exposure to the air slakes slowly to a granular mass. It also contains much soluble mineral matter.

Underlying the coal is what is known as "fire clay," which is a gray, gritty, clay shale. That it is not fire clay is however shown by the following tests:

The clay grinds up rather easily but slakes very slowly when thrown into water. It shows no appreciable amount of mica, and no pyrite.

When mixed with 18% of water it gave a mass of rather low plasticity, but one which on account of its porosity and leanness stood rather rapid drying.

The bricklets made from the shale had an air shrinkage of 4%, while their total shrinkage at cone 1, when incipient fusion occurred, was 7%, and the color was buff speckled. Vitrification occurred at 5, with a total shrinkage of 12%, the color being grayish buff. The clay became viscous at cone 8.

We see from this that the fusion of the clay takes place very slowly, and that the beginning and end points are pretty well

separated. From the fact that the clay fuses at cone 8 it cannot be considered as a fire clay. The percentage of soluble salts in it is .35%. With the shale alone we have a good material for the manufacture of pressed brick, but for making paving brick out of the material it would be desirable to mix a more plastic clay with it.

At the coal shaft one-half mile from the station in a westerly direction the character of the overlying and underlying shale is similar.

The shale or fire clay underlying the coal ten miles east of St. Charles is said to be very plastic. This occurrence is on the land of F. L. Parker, in the N. E. $\frac{1}{4}$ of Albee township, Sec. 23.

Verne.

The coal at the mines of the Verne Coal Co., 3 miles west of Verne Station, is underlain and overlain by a pyritiferous, black, shale; very brittle and containing much organic matter, including *Productus Prattenianus* and other shells. No sample of it was tested.

Flushing.

The Saginaw Clay Manufacturing Co. has a large quarry about one mile north of Flushing, which is connected with the railroad by a



Fig. 2. Shale quarry, Flushing.

switch. The section consists of a dark grayish black shale, of rather fine grain, and brittle character, see analysis 3, and a lighter gray shale of softer quality and more open texture, analysis 4. The former is spoken of as shale and the latter as fire clay. The two are separated by a thin seam of coal, which is also sent up to the brick works to be used as fuel for burning the brick. There is five feet of stripping.

The two clay materials found in the quarry correspond in general to the shales found over and under the coals at the different mines in the Saginaw region. Neither of them are soft enough to permit their extraction without the use of powder. In quarrying the shales are loaded onto cars as shown in the view, (Fig. 2.) and these are drawn to the base of an inclined plane by horse power, up which they are then hauled with a wire cable to the railroad track where they are emptied into the cars.

The two shales are mixed in about equal proportions in the manufacture of the paving brick. The upper shale is the more fusible and serves as a bond in the finished product, while the lower clay is the more plastic of the two and serves to hold the mass together in molding, and facilitate the flow of the clay mixture through the die of the stiff mud machine. Owing to its more refractory nature it also serves to keep the form of the brick during the burning when the material is heated up to the temperature of vitrification. These

Analysis No.	2.* Gray shale.	3. Black shale.	4.* Fire clay.
SiO ₂	63.00	54.50	70.55
Al ₂ O ₃	21.80	30.75	21.20
Fe ₂ O ₃	8.80	3.50	3.20
CaO.....	1.70	1.06	1.00
MgO.....	2.00	1.69	1.50
Soda.....	.79	.8	.74
Potassa.....	1.88	2.2	.90
Water.....		5.51	
Total.....	99.95	100.00	100.00

differences are brought out in the tests of the individual clays, but could be emphasized if a mixture of the two were tested.

A sample of the lower or so called "fire clay" (183) required 20% of water to work it up and gave a moderately plastic mass, whose

*Analyses from mineral resources, 1896.—Eighteenth Annual Report, Director U. S. Geological Survey, Part V, p. 68, from Saginaw Clay Manufacturing Company, H. and W. Helm, Analysts.

These analyses have also been printed in the Michigan Miner. As the absence of water shows, No. 2 and No. 4 cannot represent a natural unburned clay.

air shrinkage was 5%. When molded it showed a slight tendency to crack, unless much pressure was used. The tensile strength of the air dried briquettes was from 60 to 65 pounds per square inch, and while this may seem low, still it is no lower than that exhibited by many other shales used in the U. S. for the manufacture of paving brick. In burning incipient fusion began about cone 1 with a total shrinkage of 10%, the color of the clay being grayish buff. At cone 5 the shrinkage was 11%, and vitrification was not reached until cone 7. The color of the bricklet remained the same, but the shade deepened somewhat. The clay became viscous at cone 11. The

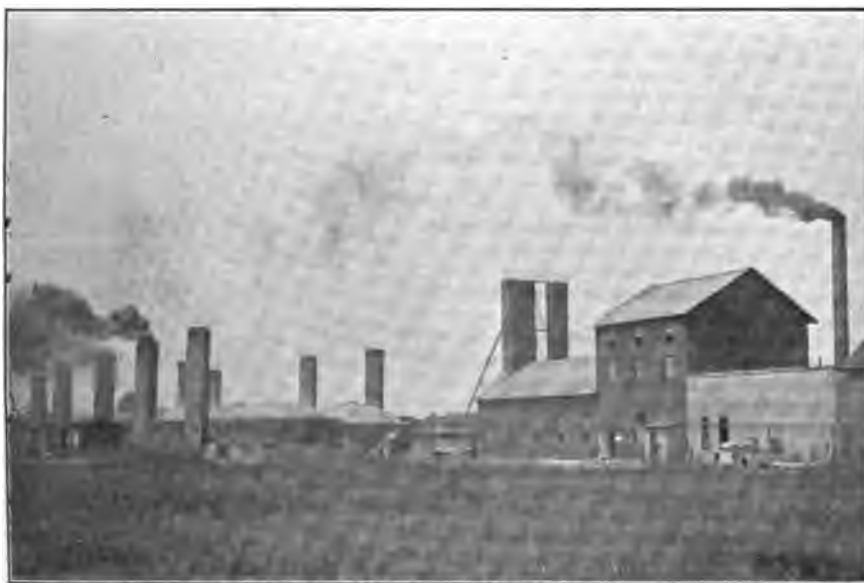


Fig. 3. Brick works, Saginaw Clay Manufacturing Co., Saginaw.

raw clay contains considerable finely divided mica, and also some concretions of carbonate of iron, which the workmen in the quarry call sulphur.

The other ingredient of the paving brick mixture, viz., the shale (222), is hard and sandy, but darker colored. The sand is often concentrated into thin seams and there is much fine grit, but little or no carbonate of lime, for the clay does not effervesce with acid. When ground to pass a thirty mesh sieve, and mixed with 20% of water, it yielded but a lean mass with an air shrinkage of 3 per cent. In burning, the clay showed a total shrinkage of 5% at

cone 05 and incipient fusion was not reached until cone 1. At this point the color was red and the total shrinkage 7%.

The brick vitrified at cone 6, and gave a total shrinkage of 9%; the color being deep red. Viscosity was reached at cone 8.

The tensile strength of air dried briquettes ranged from 35 to 40 pounds per square inch, and the soluble salts were .3%.

The process by which the bricks are manufactured consists in grinding up the shale in dry pans, and then mixing the material in a pugmill after which the bricks are molded on a stiff mud machine. The drying (about 36 hours) is done in tunnel dryers and the burning (for 10 to 12 days, and about the same time for cooling) in circular down draft kilns. A view of the works is shown in Fig. 3.

For data as to orders, contracts, etc., see Michigan Miner for April, 1900.

In order to test the effect of fineness of grinding on the shale a sample of the lower clay from Flushing was ground to pass through a sixty mesh sieve instead of 30 as was done in the first case and indeed with all the other samples tested.

This ground material took 22% of water in mixing, and the brick-lets had an air shrinkage of 5½%. The average tensile strength was from 55 to 60 pounds per square inch. In burning, incipient fusion occurred at 1, with a total shrinkage of 10%, vitrification at 5 to 6, and viscosity at 10. The effect of the finer grinding was to produce a more homogeneous tint or color in the burned brick, and to make it densify at a lower temperature, but the temperature of fusion remained about the same and the tensile strength and plasticity were not increased.

The following tests of their paving brick by the company may be of interest, though the variation in specific gravity of the brick substance shows that they are not very accurate and that probably No. 1 was not thoroughly soaked.

	1.		2.	
Weight in dry air at beginning.....	12 lbs.	12 oz.	31 lbs.	10 oz.
Weight in water dry at beginning.....	7 "	0	(17	12)†
Weight in water wet.....	7	4	18	7
Weight in air wet.....	13	0	32	5
Weight in air dry at end.....	12	12	31	10
Specific gravity of brick substance.....		2.32		2.62
Weight of brick in ozs. per cu. foot*.....		2,217		2,310
Ratio of absorption.....		1.96%		2.18%
Porosity, % of volume pores.....		4.6%		11.9%

*More precisely kilograms per cubic meter.

†Computed.

Saginaw.

Standard Mining Co., Sec. 6, T. 11, N., R. 5 E.

The shale (217) under the coal at the shaft of the Standard Mining Co. is a dense brownish shale with plant stems, and small mica scales, but with very little grit. It burns to a good red brick at cone 1. The shale when ground to 30 mesh yields a moderately plastic mass with 20% of water and had an air shrinkage of 4%. The average tensile strength of the air dried briquettes was 55 to 65 pounds per square inch. The soluble salts amounted to .2%. Incipient fusion occurred at 1 with a total shrinkage of 10%, and the clay vitrified at cone 4, and became viscous at 9. The clay burns red.

Its composition is given in the following analysis by A. N. Clark:

ANALYSIS 1, (Repeated).	
Silica	55.30
Alumina	14.20
Ferric oxide	3.62
Lime carbonate .....	.30
Magnesium "	2.61
Alkalies	2.15
Water and organic matter.....	21.82
	<hr/>
	100.00

This was probably not a thoroughly dried specimen.

In sinking a new shaft at the Standard Mining Co.'s property the following section was penetrated:

Sandy clay	90 ft.
Fine grained blue clay	10 ft.
Impure "fire clay"	3 ft.
Shale	8 ft.
Conglomerate	4 ft.
Black shale	20 ft.
Coal	
Fire clay (so called).....	6 ft.

The 8 foot bed of shale was tested as it appeared promising, and could be extracted without much trouble in connection with the coal. While this sample (220) took 23% of water to work it up, still it did not give a very plastic mass, but one whose shrinkage was low, viz. 3%. The tensile strength ranged from 30 to 42 pounds per square inch, with an average of 35 pounds.

The soluble salts were .3%.

In burning, incipient fusion occurred at cone 3, vitrification at 7, and viscosity at 9.

The shrinkage and color were as follows: -

Cone.	Shrinkage.	Color.
03.....	3%	Buff.
1.....	5%	Red.
3.....	7%	Red.
5.....	9%	Deep red.

At the shaft of the Pere Marquette Coal Co. the bed of shale overlying the coal is of a brownish black color and contains considerable organic matter. It is dense, somewhat brittle, but does not slake easily or only on long exposure to the weather. Neither mica, pyrite nor carbonate of lime were noticed in it.

The shale found over the coal at the Pere Marquette shaft No. 2 and at the Saginaw Coal Co.'s shaft is similar. Underlying the coal at these shafts is a gray sandy shale which is at times very silicious and would more properly be classed as a sandstone lithologically. In places it yields, however, considerable quantities of plastic material, which does not contain an excess of the sand.

The following represents the physical condition and behaviour of one sample from under the coal at the Pere Marquette shaft 1.

The shale required only 16% of water to work it up, giving a mass of poor plasticity as might be expected. This low plasticity was due probably to the fact that the particles are pretty well cemented together and consequently on grinding yield a granular instead of powdery mass.

The air shrinkage was 5%, and the tensile strength of the air dried briquettes ranged from 38 to 45 pounds per square inch. The soluble salts amounted to .4%.

In burning, incipient fusion began at cone 01, with a total shrinkage of 6%. Vitrification was reached at 4, with 11% shrinkage, and viscosity at 7. The shale burns deep brownish red.

Bay City.

At the mine of the Central Coal Mining company, the coal seam which is 150 feet below the surface, is overlain by a brittle bituminous shale, and underlain by a red to gray shale, varying in thickness from 2½ to 4 feet. This underclay is quite homogeneous, and resembles somewhat that found at the Standard shaft near Saginaw, but is much softer, being easily cut with the blade of a knife.

It is stated that this clay (228) was at one time tried for the manufacture of bricks at Saginaw and gave good results.

Unlike most of the other shales found with the coals in this region, it slakes in water, although slowly. It has a somewhat sandy appearance and contains numerous small mica scales.

It took 19 per cent of water to work it up to a lean but not granular mass, whose air shrinkage was 5%.

The tensile strength of the air dried briquettes was from 50 to 60 pounds per square inch, and the soluble salt contents .3%.

In burning at cone 05 the total shrinkage was 6%, but incipient fusion was not attained until cone 1, with a total shrinkage of 7%, the color of the bricklet being cream. At cone 4 the shrinkage was 9% and the color of the brick the same. Vittrification took place at 5, and above this the clay burned to a grayish color, beginning to show signs of viscosity on the part of some of the larger ferruginous patches at cone 8. The brick as a whole did not fail until cone 11.

At the mine of the Michigan Coal & Mining Co., the shale forms a layer two to three feet thick under the coal. It is soft when mined but hardens on exposure to the air. It grades downward into a bluish-black shale. Overlying the coal is an argillaceous sandstone.

The undershale resembles somewhat that found at the Central Coal Co.'s shaft. While the two types found under the coal both appear hard when dry, still they differ in plasticity as already noted, when freshly mined, and this difference also shows itself in their further physical behavior.

The upper part of the under clay (187), behaves as follows:

Water required to temper, 25%; air shrinkage of bricklets, 6%; tensile strength of air dried briquettes, 150 to 175 pounds per square inch; incipient fusion reached at 05, with a total shrinkage of 9%, vittrification at 1 and viscosity at 5. Soluble salts .2%.

The bottom layer on the other hand does not slake as readily as the preceding one. It shows no mica nor pyrite. In mixing it up only 17% of water were required, and the resulting mass was granular and lean; it could be dried rapidly without cracking. The air shrinkage was 4%, and the tensile strength of the air dried briquettes ranged from 55 to 60 pounds per square inch. The soluble salts were .7%. The clay burns red at cone 06 and vittrified at 2.

The coal at the Wenona Coal Co.'s mine is 158 feet below the surface and both underlain and overlain by shale. The underclay

has the usual term of fire clay applied to it, and is a very silicious clay shale. The over clay is similar to that used by the Saginaw Clay Mfg. Co., but has occasional streaks of bituminous brittle shale. The thickness of this upper shale is 8 to 10 feet thick in many places, but at times thins out to 2 feet.

A sample of this material (180) was tested with the following results. It gave no effervescence with hydrochloric acid, and showed little or no pyrite, but scales of mica were not uncommon in it. When thrown into water it slaked little or none.

In working it up, 18% of water were required, giving a mass of low plasticity, whose air drying could be carried on rapidly, and was accompanied by 3½% of shrinkage.

The tensile strength of the air dried briquettes was also low amounting to an average of 55 pounds. The soluble salts were .6%.

In burning, incipient fusion took place at 2, with a shrinkage of but 4%, vitrification at 6, and viscosity at 8. The shale burned red.

At the shaft of the Monitor Coal Co. the overlying shale is similar to that at the Wenona Coal Co.'s shaft (which see) but contains more bituminous matter. It has somewhat less resemblance to the shale used at the Saginaw Clay Mfg. Co.'s Works. The so called fire clay underlying the coal is similar to that quarried in the quarry at Flushing, and used in the paving brick mixture at Saginaw. A car-load of the two shales was sent to Saginaw some time ago, for testing, and found to yield very favorable results. The fire-clay at this mine is said to average 8 to 10 feet in thickness and the shale 10 to 21 feet.

The Bay Coal Co. also has shale under its coal, as well as over it, which in its general character resembles the preceding very much. It is said to be four feet thick.

The following analyses by A. N. Clark give an idea of the nature of the shales above described:

Analysis No.	5	6.
SiO ₂	52.45	57.10
Al ₂ O ₃	23.27	20.02
Iron as Fe ₂ O ₃	7.93	8.18
Lime as Ca CO ₃	1.82	0.71
Magnesia as Mg CO ₃	1.06	1.47
Alkalies as K ₂ O.....	4.37	2.76
Difference, largely H ₂ O and organic.....	9.10	9.76
Sum.....	100.00	100.00
Ferrous iron as FeO.....	1.57	1.47

No. 5, field No. 12. (180.)
No. 6, field No. 6. (187.)

Jackson.

Not much has been done on the shale around Jackson. Judging from the analysis the clay of G. H. Wolcott's yard in Springport township is practically a coal measure shale. (Analysis 31.)

Sebewaing.

The Michigan Standard Coal Co. has a shaft at the southern end of the town at which the coal is interbedded with shale.

That over the coal is a brittle black bituminous shale with numerous nodules of pyrite, while that under the coal is gray and sandy. On exposure to the air it slakes readily to lumps the size of a hazel nut, but to get it finer requires grinding. Some of it was tried at the neighboring brickyard, and it was not found possible to melt it in the scove kilns.

It was consequently thought desirable to test it physically.

The sample collected (182) gave no effervescence with acid, and slaked very slowly in water. When mixed with 17% of water it gave a mass of good plasticity whose air shrinkage was 5%, and the air dried briquettes made from it had an average tensile strength of 100 pounds per square inch with a minimum of 90 lbs.

In burning, incipient fusion began at cone 1, with a total shrinkage of 8%, the color being buff. It vitrified at 5, and became viscous at 9. The shrinkage at vitrification amounted to 13%. The soluble salts were .25%.

Grand Ledge.

Near Grand Ledge are the most extensive exposures of the coal measures naturally in the state. The shales are exploited by the Grand Ledge Sewer Pipe Co., Frank A. Taber, Secretary. Their principal product is vitrified sewer pipe of dark color and good quality. A full description of this region was given by Dr. Rominger.*

The works are close to the N. E. corner of Sec. 10, T. 4 N., R. 2 W. and their raw material is mainly derived from pits about a quarter of a mile north, close to the Spiritualist camp meeting grounds, at the summit of a bluff overlooking the valley of Grand River and a small tributary creek. The section is:

| 3 feet stripping of till.

*Geol. Sur. Mich., Vol. III, Part I, p. 131.

7 | 4 feet grey shale.

8 | 1 foot black shale passing into coal.

10 | 2 feet white shale, so called fire clay. The lower line of this white shale undulates so as to indicate that it is merely an alteration of the shale below.

14 | 4 feet blue shale. This and the shale above the coal both contain nodules of kidney iron ore, sometimes showing some zinc-blende. This also shows traces of ferns, *Sphenophyllum cuneifolium*.

15 | 1 foot darker shale, the floor of the shale quarry.

Below in the bluff the section is continued by twenty feet of light and dark thin bedded sandstones or sandy shales, readily checking or cracking and slaking on weathering, down to a foot and a half of coal, which is the seam that is worked in a series of adits to the north, clear to and beyond the town line, at about the same level of ten or fifteen feet above the stream. The analyses of the darker and lighter shales from this pit are Nos. 7 and 8.

South of the works there is also a pit which lies much lower, in the valley of a stream and filled with water when not in use, which seems to be below the bed of coal. It is also said to be of different quality from the other, and richer in ferns. The section is:

15 feet cross-bedded sandstones.

17 | 2 feet coal with *Lingula mytiloides* just above and ferns just below.

20 | 3 feet white shale.

The coal measure shales are also exposed near Williamston and in Chester township of Eaton county, but have not been exploited.

Analysis of shale from Spiritualist camp meeting grounds, Grand Ledge, Mich., A. N. Clark, analyst.	7. Black Carboniferous Shale.	8. Grey Carboniferous Shale.
SiO ₂	44.30	57.20
Al ₂ O ₃	23.72	18.96
Fe ₂ O ₃	7.68	8.31
CaO.....	1.11	0.83
MgO and Mn ₂ O ₄	1.50	1.83
K ₂ O and Na ₂ O.....	2.00	2.70
H ₂ O and organic matter.....	17.64	9.00
CO ₂	2.36	1.32
SO ₃		0.12
Sum.....	100.31	100.26

P₂O₅ is probably included with alumina.

§ 6. Michigan series of shales.

The shales of the Michigan series form a belt 10 to 20 miles in width, surrounding the area of Carboniferous rocks in the Lower Peninsula. They are, however, best exposed at Grand Rapids, where they form a bed of 6 to 10 feet thick overlying the gypsum. They are also exposed in Huron county and Arenac county, and in Tuscola county along the Cass River where it has been proposed to exploit them for the manufacture of Portland cement.

Grand Rapids.

The character of the shales associated with the gypsum can be well judged from its occurrence at two localities in this vicinity,



Fig. 4. Shale and gypsum quarry. Alabastine Co., Grand Rapids.

viz.: at the shaft of the Powers Plaster Co. and in the quarry of the Alabastine Co., Fig. 4.

In order to determine the degree of variation at this locality, samples were examined from both of these points.

The first was taken from the shaft of the Powers Plaster Co. (216), and this was a dense, brownish gray shale, containing but little mica, and no pyrite, and slaking with extreme slowness, although it mellowed down slowly when exposed to the air. In tempering the material and working it up, 26% of water was needed, the brick-

lets made from this having an air shrinkage of 6%, and the air dried briquettes ranging in strength from 130 to 155 pounds per square inch.

Incipient fusion occurred at 05 with 12% total shrinkage, vitrification at cone 2 and viscosity at cone 6.

The shale burned to a good red color. The soluble salts amounted to .9%.

The second sample (227) was taken from the quarries of the Alabastine Company, at Grand Rapids, (Fig. 4), where it forms a bed 7 feet thick overlying the gypsum. The shale is itself covered by three feet of drift material.

At present the shale is used in the manufacture of common brick. Before molding it is spread out under a shed to dry and slake, after which it is ground in a dry pan and tempered. The molding is done by the stiff mud process.

This shale like the preceding sample shows no pyrite or mica, and when fresh slakes very slowly in water.

When ground to 30 mesh, it mixed up to a very plastic mass requiring 32% of water. The air shrinkage of bricklets made from this mixture was 6%. The average tensile strength of air dried briquettes was 105 pounds, with a maximum of 110 pounds. The soluble salts amounted to .9%. In burning, the bricklets were a good red, which of course deepened with harder firing.

Incipient fusion occurred at 05, vitrification at 01, and viscosity at 3. At the first of these points the total shrinkage was 12%, and at the second one 16%.

The high percentage of soluble salts caused a white scum to form on the bricks in drying, but this could be prevented by the use of barium chloride or carbonate.

Compare the analysis of this clay from Grand Rapids by S. P. Sharpless, cited in Mineral Resources for 1895,* to wit:

ANALYSIS 9.

SiO ₂	58.70
Al ₂ O ₃ +Fe ₂ O ₃	25.95
CaO.....	1.00
MgO.....	.74
Alkalies.....	5.54
Water, etc.....	8.07
Sum.....	100.00

*Sixteenth Annual Report of Director U. S. G. S., Part IV, p. 566.

Analysis No. 10 is also from Alabastine opening, and will be seen to resemble No. 9 strongly. It is of sample No. 20 by A. N. Clark.

ANALYSIS 10.

SiO ₂	56.50
Al ₂ O ₃	19.31
Fe ₂ O ₃	5.89
CaCO ₃	1.00
MgCO ₃	1.85
Alkalies (K ₂ O)	5.98
Difference	9.47
	<hr/>
	100.00
Ferrous iron as FeO separately	1.34

Another analysis of shale clay made by Prof. Kedzie from this formation north of Saginaw Bay is very similar, but with less alkalies, (?) salt.

§ 7. Coldwater shales.

The Coldwater shales are perhaps the most extensive in the state, and from the economic standpoint have thus far been the most important, because they are the source of supply of all the Portland cement factories of Michigan. They have been quarried chiefly at Bronson, Union City and Coldwater, but extensive beds also occur at Quincy. At these three points the shale is fine-grained, soft, and weathers rather easily to the clay-like mass. The composition of that used at Bronson is:

ANALYSIS 11.

	Per cent.
Silica	62.10
Alumina	20.09
Ferric oxide	7.81
Lime .....	.65
Magnesia .....	.96
Sulphuric acid .....	.49
Water and organic matter	7.90
	<hr/>
	100.00

The shales of this series show, so far as the tests go, the properties desirable in the manufacture of vitrified wares. They also burn to a good red color, and vitrify at a moderate heat.

Union City.

This shale has been utilized for the manufacture of Portland cement, but is likewise capable of being employed for other purposes.

The shale which (218) is obtained three miles to the southeast of the town is similar to that used at Bronson, at least as far as appearance goes.

It contains little or no carbonate of lime, as it produces no effervescence with hydrochloric acid. Neither does it show much pyrite. In working it up, 25% of water were required, and yielded a moderately plastic mass, whose air shrinkage was 5%. The air dried briquettes had a tensile strength of from 70 to 80 pounds per square inch, which is rather low.

The soluble salt content was also low, amounting to .4%.

The clay burns bright red, which deepens as vitrification is approached. Incipient fusion was reached at 05, and vitrification at 2, the shrinkage at these two points respectively being 9% and 13%. Viscosity occurred at cone 5.

Quincy.

A sample of shale from the property of H. Bennett (219) and representing the average of his deposit as exposed in the creek mentioned, gave the following results:

The shale when fresh is dense and hard, but weathers down to a clay which is tough and plastic and contains little grit. It does not effervesce with acid, and shows no mica nor pyrite.

Only 19% of water were required to mix it up, and the mass obtained was moderately plastic. The shrinkage of the bricklets in air amounted to 4%, and the average tensile strength of the air dried briquettes ranged from 75 to 80 pounds per square inch.

The soluble salts were only .2%.

In burning to cone 05, the total shrinkage was 6%; at cone 03, 8%; the clay fused incipiently at the last point. It vitrified at cone 3 with 12% shrinkage, and viscosity took place at 6.

Coldwater.

This shale is also used in the manufacture of Portland cement, the portion quarried being the weathered part of the bed. The material is mostly fine grained, containing but little grit, and the lumps slake slowly when thrown into water. The shale yields no effervescence on the addition of muriatic acid, but carbonate of iron concretions are at times found in it.

In working it up for molding, 21% of water were required, and this gave a mass of very fair plasticity and ability to stand rapid drying. The air shrinkage was 7%, and the air dried briquettes had a tensile strength ranging from 125 to 139 pounds per square inch. In burning, incipient fusion was reached at 03 with a total shrink-

age of 14%, the brick burning to a good red color. At cone 1 the brick became deep red and vitrified at 2 with a total shrinkage of 16%. Viscosity was reached at 5.

If heated too fast there was danger of warping the bricklet. The shale contained a trace of soluble salts.

The partial composition of the Coldwater shale is:

ANALYSIS 12.

Silica	53.44
Alumina and ferric oxide	24.80
Lime .....	.76
Magnesia .....	.25
Difference	20.75
Sum	100.00

Bronson.

This shale (230), which is obtained from the Cuyahoga formation, like many other deposits found in this state is at present used chiefly for the manufacture of Portland cement. It is being mixed with marl for that purpose. It would seem, however, that it has marked possibilities in other directions and consequently a sample of it was taken from the stock pile of the Portland cement works at Coldwater, and subjected to a physical test, which yielded the following results: The shale itself is dark gray in color, somewhat dense, but not very hard, and when exposed to the water breaks down into a rather plastic clay.

When ground to pass through a 30-mesh sieve it required 31% of water to work it up into a moldable mass which was very plastic. But in spite of its high plasticity large bricks which were made from it and subjected to rapid drying did so without showing signs of cracking. The air shrinkage of bricklets made from this mixture amounted to 6%. In the burning of the material the temperature had to be raised very slowly in order to prevent the brick from cracking and swelling as it contained a high percentage of organic matter.

The following figures show its behavior under fire:

At cone 06, total shrinkage 12%, color red, incipient fusion; at cone 03, total shrinkage 15%, color red, bricklet nearly vitrified, at cone 1, total shrinkage 16%, color deep red, vitrification reached.

At cone 2, viscosity begins.

In spite of its high plasticity, bricks made from this mixture did not show a very high tensile strength, this latter ranging from 100 to 125 to 135 pounds per square inch.

The soluble salts amounted to .5%.

Analysis 11, above, is the composition of this material quoted from "Mineral Industry" Vol. VI:

White Rock.

Excellent exposures of Coldwater shale occur along the shore of Lake Huron between White Rock and Forestville (Plate I), but they have not thus far been utilized.

The shale forms a line of cliffs, and when fresh appears brittle and gritty; in places, however, it has mellowed down to a tough clay.

The rock is a thinly laminated shale (179), which contains much sand of a very fine nature, and slakes slowly along the layers. It worked up with 19% of water to a mass of fair plasticity. The brick-lets had an air shrinkage of 4%, and the briquettes had a low tensile strength of 36 to 42 pounds per square inch.

Incipient fusion took place at 03, vitrification at 3, and viscosity at 6. The total shrinkage when in the vitrified condition was reached was 11%, the color being deep red.

An analysis of this material yielded:

ANALYSIS 13.

Silica	58.70
Alumina	18.31
Ferric oxide	7.19
Lime carbonate	1.80
Magnesium .....	.98
Alkalies	3.67
Water and organic matter	9.35
	<hr/>
	100.00
Ferrous oxide	2.73
Total fluxes	13.64

§ 8. Devonian shales.

Some of the promising shale exposures in the State are those outcropping to the southeast of, and around the village of East Jordan. They weather to a tenacious clay, and burn to a good red color. Like the Branch county Coldwater shales, they show evidence of the presence of considerable soluble salt, and this would have to be looked after in the manufacture of certain grades of clay products.



SHALE AT WHITE ROCK, NEAR FORESTVILLE.



SHALE OUTCROPS NEAR FORESTVILLE.

In part at least they probably belong to the Devonian (St. Clair) shales, but the Berea Grit which divides the Coldwater shales from the St. Clair shales, has not been located in this part of the state.

East Jordan.

Some years ago a shaft was sunk on the property of J. H. Kocher about five miles south of East Jordan, on the W $\frac{1}{2}$ of N. E. $\frac{1}{4}$, Sec. 30, T. 31 N., R. 6 W.

In the sinking of the shaft which is 105 feet deep a number of shale layers were penetrated, which were mostly of a grayish-black color due to the organic matter which they contained, those near the bottom of the shaft containing considerable quantities of small selenite crystals, but no pyrite was noticeable. While the shale weathers down to a clay on exposure, the fresh pieces slake but slowly splitting along the layers.

The shale (185) contains a high percentage of soluble salts (.8%), which form a white coating on the surface in drying. In working up the shale for molding, 20% of water was required, and even then the mixture was only moderately plastic. The air shrinkage was 5% and had to be carried on slowly to avoid cracking. The tensile strength of the air dried briquettes was from 70 to 80 pounds per square inch.

In burning, the clay burned red at 05, with a total shrinkage of 7, but incipient fusion was not attained until 01.

The clay had to be heated very slowly, until all the organic matter had been expelled. Vitrification took place at cone 3 and viscosity at 6.

Another good locality for examining the shale of this region occurs along the road on Sec. 13, between the lumber camp of the East Jordan Lumber company, and the town of East Jordan. There are several outcrops of shale which in places are weathered to a depth of 10 or 15 feet. A sample (177) was taken from the cut in the road near the camp, and the material is a tough reddish clay, which is similar to that being worked in the brickyard at East Jordan.

It is very fine grained and slakes freely in water, but gives no effervescence with acid. It contains .8% soluble salts, which appear on the surface in drying and burning. The air shrinkage was 7%, and had to be carried on slowly. Incipient fusion occurs at 05, vitrification at 01, and viscosity at 2.

The clay burns to a deep red and makes a very smooth brick.

The total shrinkage at vitrification was 13%. The tensile strength of the air dried briquettes was from 80 to 95 pounds per square inch. The following analysis (14) of the material was made by A. N. Clark. No. 15 is also from these shales:

Analysis No.	14.	15.
Silica.....	55.93	58.60
Alumina.....	17.43	17.66
Ferrie oxide (all iron as).....	7.67	7.44
Lime carbonate.....	2.14	2.14
Magnesium carbonate.....	1.55	2.19
Alkalies as K ₂ O.....	2.86	.....
Water, organic matter and difference.....	12.40	11.97
	100.00	100.00
Ferrous iron as FeO.....	0.50	.....

Norwood.

Along the lake shore about one half mile south of Norwood are extensive outcrops of a dark shale, which is thinly bedded, and traversed by numerous joint cracks. The beds vary somewhat so that by searching along the shore it will be found that the material is softer at some localities than others. A sample (176) was taken from the bluffs along the shore one-half mile south of the landing at Norwood. It works up with 24% of water to a very plastic but not sticky mass, which had an air shrinkage of 6%. The drying had to be carried on slowly to prevent cracking, and in the early stages of the burning, great care had also to be taken. In burning the incipient fusion of the clay was reached at 02, with a total shrinkage of 12%, vitrification at 1 with 14% shrinkage and viscosity at 3 which is rather low. The tensile strength of the air dried briquettes was very good, ranging from 135 to 150 pounds per square inch, and the soluble salts were .6%. This is almost certainly the St. Clair shale.

There are, no doubt, many other localities around Charlevoix and E. Jordan, which would yield material suitable for the manufacture of common, pressed or vitrified brick. In addition the intervening lowlands contain beds of clay which have been formed by the wash from the shale outcrops on the hillsides. In some cases these are associated with marl.

Clay also occurs 1½ miles southwest of Boyne Falls on the property of J. F. May, and on the land of Mrs. Powers. The lower layers of the deposit on this latter property it is said, have been

tested for pottery purposes, but the upper layers when burned into brick showed a tendency to crack.

Another analysis given below of the St. Clair shale is probably of the fresh material from which the East Jordan and Norwood clays are derived by a process of weathering, involving loss of the volatile combustible. This analysis was given by W. H. Johnson of Alpena and as its form shows was also intended to test the fuel value.

ANALYSIS 16.

Volatile matter	17.96
Fixed carbon	6.49
Ash	75.55
	<hr/>
	100.00

ANALYSIS OF ASH.

Silica	70.54
Alumina	15.33
Ferric oxide	5.31
Lime	2.38
Magnesia .....	.78
Alkalies, etc., by difference.....	5.56
	<hr/>
	100.00

The ratio of silica to alumina is unusually high. That of alumina and iron remains fairly constant in all these shales, at not far from 3 to 1, but here the iron is somewhat in excess.

§ 9. Hamilton (Traverse) shales.

Deep wells passed shale in this group according to many of the records compiled in Vol. V of this report. Much of the so called soapstone is calcareous shale. Such shales are heavily covered with drift in the lower part of the state and no important seams are reported near the surface around Little and Grand Traverse Bay, although the Petoskey and Charlevoix deep wells passed through well marked beds of shale at considerable depths. Only around Alpena do these beds appear to come to the surface in available shape. Out at the end of Third street, Alpena, is a smooth unctuous clay, which effervesces freely with acids and hence is too calcareous for many uses, which appears to come out from under a limestone and to be a calcareous shale which has slaked in weathering.

The Alpena Portland Cement Co., have, however, a clay shale outcropping several miles north of Alpena, and hence probably about the horizon of the Marcellus shale which is between 400 and 500 feet down at Alpena. The dip in that region is about 42 feet per mile to the southwest. From the analysis it will probably be a good clay not only for cement but for high grade brick in general. The analysis is as follows:

ANALYSIS 17.

Silica	61.09
Alumina	19.19
Iron as ferric oxide	6.78
Calcium oxide = (4.48CaCO_3)	2.51
Magnesium oxide .....	.65
Potassium oxide	1.80
Sodium oxide	1.86
Sulphuric anhydride	1.42
Water and CO_2	5.13
	<hr/> 99.93

§ 10. Hudson river shales.

The Hudson river shales, which outcrop abundantly at some points of the Upper Peninsula, especially to the northeast and east of Escanaba, are too highly calcareous and too silicious to be of any value in the making of clay wares.

A series of analyses by Prof. G. A. Koenig, of the Michigan College of Mines, of samples from bluffs in this region showed a series of calcareous shales, and argillaceous limestones. Some of the layers had the right composition for natural cement rock, but the composition did not seem to be regular, either horizontally or vertically.

From a well recently put down at St. Ignace, I have samples down to 1,008 feet and I judge that it entered the Trenton limestone, (though the separating line is by no means clear) probably at about 1,044 feet depth. The Niagara seems to extend from 426 to 788 feet, but between that and the bottom there are no marked shale beds. Brown dolomitic limestones predominate.

See also Geol. Sur. Mich., Vol. I. Part III, pp. 50 to 56, by Carl Rominger. L.

§ 11. Surface clays.

All of the soft plastic clays occurring in the state are of Quaternary age, but still divisible into three types, viz.: morainic or drift clays, lake clays, and river silts.

The former include those deposits of rather local extent, which form masses of often lenticular shape, enclosed within drift material. Among these may be mentioned the occurrences at Lansing, Ionia, Kalamazoo, and possibly Harrietta.

The glacial clays are invariably calcareous, while the lake clays are very frequently so. The river silts are less likely to be calcareous, but are usually gritty. A noteworthy fact is that there is often a division into two members, viz., a lower very calcareous cream burning one and an upper less calcareous one from which the lime has perhaps been leached by weathering, which burns red. This was noticed at Detroit, Lansing, Sebawaing and Minden City, and may hold true at other localities. At most points, however, the deposits are worked only on a small scale and consequently the clay pit seldom extends below the bottom of the upper member.

The number of localities at which surface clays are worked is very great and consequently but a few of them could be visited in the time available.

The calcareous composition of the surface clays is shown by the

following analyses, No. 18 being of clay from the Prairie farm near the junction of the Flint and Shiawassee Rivers from C. A. Davis, and No. 19, from near Grayling, No. 20 from Middle Lake; these latter we owe to the kindness of Wm. M. Courtis, C. E.

Analysis No.	18.	Analysis No.	19.	20.
SiO ₂	58.50	SiO ₂	52.35	55.35
Al ₂ O ₃	18.69	Al ₂ O ₃	14.90	17.89
Fe ₂ O ₃	11.46	Fe ₂ O ₃	5.60	6.86
CaO.....	1.75	CaCO ₃	15.10	7.25
MgO.....	10.98	MgCO ₃	5.75	2.65
CO ₂ , computed.....		SO ₂.....	.34	.86
		H ₂ O and org.....	3.95	1.25
		Alk. and loss.....	1.61	3.75
				4.14
			100.00	

We may also include the analysis of a Marquette clay from Min. Res. Mich. 1889, p. 61.

ANALYSIS 21.

SiO ₂	54.62	CaO.....	13.68
Al ₂ O ₃	12.82	MgO.....	4.25
Fe ₂ O ₃	2.	H ₂ O, CO ₂ and loss.....	12.01
			100.48

The analyses of Clippert and Spaulding's clay (30), of some of Shepherd's clay (27, 28, 29), of the Henrietta clay (24), and the slip clays (32, 33), and Nos. (22, 23, 40, 43), are all of the same type. The surface clays have a strong tendency to have from 20 to 40% of carbonates.

The lake clays are those deposited during former extensions of the Great Lakes and often underlie large areas as at Detroit, Pt. Huron, South Haven, Marquette, Saginaw, Escanaba, and many other points along the Lake shores of the lower and even the upper Peninsula.

Detroit Clays.

The region around Detroit forms one of the most important brick making centers in the state, for surrounding the city large areas are underlain by lake clays of two types namely, the upper bed of sandy, calcareous clay and a lower very plastic material. At Wolf's and Clippert's yards for example, the upper bed averages six feet while the under bed is at least four feet thick, the bottom of it not having been penetrated thus far. The lower clay is not equally worked although it is the least fusible of the two.

A sample of both of these was tested with the following results

Upper clay from Clippert Bros., yard.

This clay shows its calcareous nature by the free way in which it effervesces when a drop of HCl is put upon it. When a lump of it is thrown into water it slakes very fast, falling down to a powdery mass. The clay, while it contains a considerable amount of very fine grained sand, is at the same time highly plastic. Some idea of the fineness may be obtained from the fact that when we wash it through a 60-mesh sieve there remains only a 2% residue, while none remains on the hundred-mesh sieve and on the 150 mesh sieve there was but about 2% residue also. When worked up into bricks this clay required 24% of water by weight. These bricklets in drying had a shrinkage of 4%. When heated to cone 05 the total shrinkage was 6% and the color of the briquette was red; at cone 01 the bricklet showed incipient fusion with a total shrinkage of 14% and the color buff; vitrification occurred at cone 2, the color being reddish buff, while the clay became viscous at cone 4.

The soluble salts in the clay amounted to .6%, and the tensile strength was fairly high, but it was difficult to obtain bricks which were free from flaws owing to the high plasticity of the material, nevertheless the average strength obtained per square inch was from 150 to 190 pounds. This clay is used to a large extent for the manufacture of common building brick. The usual process of treatment is to mix the material with some sand if necessary, although it is not usual. It is tempered out in soak pits which are rectangular in form and rather shallow and after remaining over night in this and becoming soaked with the proper quantity of water it is transferred by means of wire conveyors into the molding machine, which are of the soft mud type. The bricks are with few exceptions burned in scove kilns. One or two of the yards in this region employ stiff mud machinery, and also drawers for evaporating the moisture from the product.

Lower clay, Detroit.

This is an extremely plastic, bluish clay, which contains but little grit. It does not slake quite as rapidly as the upper clay, but contains a greater proportion of fine clay particles. When mixed with 26% of water it yielded bricklets that had a shrinkage of ?%. In burning these briquettes the incipient fusion occurred at cone 05 with a total shrinkage of 9% and the clay showing a greyish red color. The vitrification occurred at cone 1 with a total shrinkage of 15%. The clay became viscous at cone 5. The tensile strength of air-dried bricks ranged from 175 to 190 pounds per square inch

and the soluble salts in the clay amounted to 4%. This lower clay would no doubt yield a denser brick than the upper one, but owing to its dense nature in the raw condition and owing to the low percentage of sand it is much harder to work.

Monroe County.

Prof. Sherzer finds* that the clays used in this county are generally superficial river silts and lake clays, a few feet thick. They burn to a cherry red. There is some trouble with lime pebbles.

Ionia.

The glacial drift at this locality contains considerable amounts of calcareous clay and much is also found underlying the valley bottom. Two branches of the clayworking industry are based on this occurrence, viz., a brick yard and a pottery. Although the clays used appear very similar in their raw condition, still that used for the bricks cannot be employed for the pottery.

The pottery at Ionia is operated by Sage & Dethrick, and the product consists of earthenware, flower pots and saucers. The clay used is found on the opposite side of the valley from the town at the base of the hill near the penitentiary. It is a fine grained, highly plastic, blue clay, having very little grit so that most of it passes through a 150 mesh sieve. In water it slakes moderately fast to a flocculent mass. It needed 28% of water to work it up, yielding a mass of high plasticity, and with no grit. The air shrinkage amounted to 8½%, and the air dried briquette had an average tensile strength of 150 to 170 pounds per square inch. The clay contained .2% of soluble salts.

In burning, incipient fusion occurred at 05 and vitrification at cone 1 to 2. The clay burns cream white, and at incipient fusion is still quite porous.

In manufacturing the earthenware at Sage & Dethricks the clay is brought from the bank and stored in bins ready for use, and then put through a pair of rolls, from which it passes to a pugmill. At the discharge end of the latter there is fastened a heavy wire netting with meshes about one quarter inch, and forcing the clay through this tends to give an additional amount of tempering and also to destroy any lumps that be in it. From the pugmill the tempered clay goes to the molding room.

*Geol. Sur. Mich., Vol. VII, Part I, pp. 187 to 190.

The larger sized pots and saucers are jollied,* but the small ones are pressed in steel molds.

The kilns are up draft and fired by wood, and the ware is commonly cream colored, being burned at about cone 05.

At the brickyard of F. H. Van der Heyden, the clay forms a high bank, (Plate II) involving the following section beginning at the top:

Sand	2 ft.
Fat clay	6 ft.
Gravel	2 ft.
Sandy clay	12 ft.

A mixture of the upper and lower clay is commonly used as it gives the best results. A sample of this was tested (181).

Its fineness is shown by the fact that when washed through a 100 mesh sieve, but a few grains remained on the former, and only 5% of fine sand on the latter. In tempering only 18% of water was required, but this yielded a mass of high plasticity. This shrinks in the air 6%, and at cone 05 incipient fusion was just about reached, with a total shrinkage of 7%, and the color creamy white. At cone 1 the total shrinkage was 12%, and the color buff. Vitrification took place at 2 and viscosity between 3 and 4.

The clay is used for making brick, and owing to its high plasticity tends to laminate when molded in a stiff mud machine. The yard is equipped with two different brick machines, viz., a Wallace stiff mud augur machine with a triple die, and a Creager soft mud machine. The latter is used for the lower sandy clay, while the mixture of the upper and under clay is molded in the auger machine. The soft mud bricks it is said stand the weather much better. The Creager machine has the clay prepared for it in a six foot pug-mill and a pair of rolls.

The yard is also equipped with a hand power repress and the product includes some tile.

For purposes of chemical comparison analyses of the brick clays 22, and the pottery clay 23, by A. N. Clark are here given:

*A special mode of manufacture, in which the ware is turned on a wheel, but shaped in a plaster mold, the inside of the ware being shaped by a scraper, or "shoe." See Geol. Ohio. Vol. VII, p. 102.



DRYING YARD, AND



CLAY BANK, VAN DER HEYDEN'S YARD, IONIA.

Analysis No.	22.	23.
Silica.....	44.15	40.15
Alumina.....	10.00	11.25
Ferric oxide.....	4.08	4.58
Lime carbonate.....	24.64	21.43
Magnesium carbonate.....	1.50	8.93
Alkalies.....	1.55	2.06
Org. matter.....	1.95	2.06
Water by difference.....	12.13	9.25
	100.00	100.00

Harrietta.

There are two extensive outcrops of clay at this town, the one to north of the village at the brickyard of Geo. Heath, and the other in the ravine near the water tank just east of the railroad station.

The clay used at the brickyard consists of two beds, an upper and a lower member, the former burning buff on hard firing and light red when lightly fired, and a lower member which burned cream.

The clay as a whole is fine grained, tough and contains lime pebbles scattered through it.

A sample of the bottom clay which was tested gave the following results: When thrown into water it slakes rather readily, and most of the slaked mass passes through a 100 mesh sieve. When mixed with 29% of water it gives a very plastic mass, which has a high tensile strength, but owing to its fatness it was hard to mold briquettes from it that were free from flaws, and while some ran as high as 275 pounds per square inch, the majority did not exceed 175 to 200 pounds.

The air shrinkage of the bricklets made from the clay was 8% and at cone 05, 10 per cent. The clay showed incipient fusion at 1, with a total shrinkage of 17%, while vitrification followed at 3, with a total shrinkage of 22%, viscosity coming at cone 5. The color of the burned clay was as follows, at cone 05 and 1, cream; at 3, greenish yellow.

The upper clay shrinks nearly as much. A determination of the soluble salts in the clay yielded .2%, which is not excessive. Owing to its high plasticity it was hard to dry large bricks of the clay rapidly without having them crack.

The upper clay at this bank is similar to the lower one in its general behaviour. It slakes as easily, but contains slightly more sandy residue. It took 30% of water to work it and gave a very plastic

mixture whose air shrinkage was 7%. In burning, incipient fusion began at 04, with a total shrinkage of 11% vitrification at 1, with a total shrinkage of 17% and viscosity at 4. The clay burns nearly white at 05, and buff at 1.

The method of manufacture used at Heath's yard consists in feeding the clay mixture into a pair of rolls, from which it passes to a Kells stiff mud machine. Drying is done on an open yard, and burning in a scove kiln. When burned some of the bricks are buff to cream, while others are red, and a third lot are speckled cream and red.

There is an additional bed of clay a little east of the town, and which is exposed in several ravines. The best one is in a small ravine which is dammed to supply the Ann Arbor R. R. tank, and according to A. C. Lane is opposite to it on the S. E. $\frac{1}{4}$ of Sec. 7, T. 22 N., R. 11 W. The dam is about at the bottom of the clay which is underlain by a recently formed sandstone. The clay is free from grit is readily fusible, and reddish or greenish in hue. "It lies under a terrace which rises nearly 100 feet above the railroad track, and is cut by the valley which is one of the headquarters of the Slagle river. The clay is overlain by two feet of very fine sand.

The clay is on the property of J. Z. Stanley, who had it analyzed through J. H. Barnes with the following results:

ANALYSIS 24.	
Silica	42.85
Alumina	9.87
Ferric oxide	3.43
Lime carbonate	25.55
Magnesium carbonate	13.23
Water, alk., etc.	5.07
	<hr/>
	100.00

S. Geijsbeek who has also examined the clay, reports that it is probably best fit for a slip clay.

Saginaw.

Underlying the surface in the region around Saginaw, or at times covered by a few feet of sand are several beds of soft plastic clay, many of which are well adapted for brick or pottery. In the sinking of a new shaft at the mine of the Standard Mining Co., a bed of blue clay 10 feet thick was struck, (see p. 33) of which the following are the properties (212): The clay is rather fine grained, all

of it passing through a 100 mesh sieve. It effervesces slightly with acid, showing the presence of some carbonate of lime, and it also contains some lime pebbles. But it occurs at the base of the drift and the analysis suggests that it may be slaked shale. Analysis No. 16 is probably a fairer representative of the surface clays.

In working it up 33% of water were required, giving a very plastic mass whose air shrinkage was 7%.

Incipient fusion took place at 05, and vitrification at 01, with a total shrinkage of 18%. Viscosity occurred at 3.

The tensile strength is 105 to 110 lbs, and it contains .2% soluble salts.

Its composition is:

ANALYSIS 25.

Silica	47.75
Alumina	17.60
Ferric oxide	9.13
Lime carbonate	2.60
Magnesium carbonate .....	.70
Alkalies	2.21
Water and organic matter.....	22.01
	<hr/>
	100.00

There are a number of brickyards working surface clays near Paines and making light colored brick.

Clare County.

The following is an extract from a letter from W. H. Shepard concerning some of his clays. Nos. 2, 3 and 4 it will be noticed were the usual surface calcareous clays, while No. 1 is quite different, would make a red brick, and if not gritty might do for Portland cement.

"Enclosed I hand you analyses. Clay No. 1, lies at top of Nos. 2 and 3. No. 4 is from just above or at outcrop of marl on flats and I presume extends under marl for short distance at least. I think I have quite an acreage of the No. 1 clay that will analyze quite uniform throughout the entire strata as I have bored quite a number of 2½ inch holes into it and taken samples. Have a little different clay at tops of some of the highest grounds."

CLAY ANALYSES—SECS. 8 AND 9, T. 17 N., 4 W.—MADE BY H. & W. HEIM, OF SAGINAW.

	26. Clay No. 1.	27. No. 2.	28. No. 3.	29. No. 4.
Silica (SiO_2).....	65.05	47.60	45.60	50.40
Alumina (Al_2O_3).....	25. }	15.	15.85	22.10
Iron (Fe_2O_3).....	5.80	28.29	28.82	24.
Calcium carbonate.....	2.05	6.00	8.60	.52
Magnesium carbonate.....	.40			

Kalamazoo.

In the vicinity of the city there are several occurrences of surface clay, all of them closely resembling each other. They are utilized at present for the manufacture of common brick, but still are capable for making better products in some cases.

One of these deposits is worked at Wait's yard on the western edge of the town. This clay bank is a shallow deposit resting on sand which also forms the hills between which it lies. The clay burns red.

Another but larger deposit is at Leonard's yard along the South Haven branch of the Michigan Central railroad, six miles from the city (Plate III). Here the clay, which is said to be 14 feet thick, is divisible into two benches, viz., a lower one which is quite fat and an upper more sandy one. A mixture of the two is employed for making common brick.

In the manufacture the clay is tempered in ring pits and molded in soft mud machines. The drying is done on pallets and the burning in scove kilns.

A sample of the mixed clays from this deposit was tested (223), and was found to be one of the most plastic of the whole series collected in the present investigation. It took 23% of water to work it up, which is a low amount considering the high plasticity. The bricklets had an air shrinkage of 6%. Incipient fusion began at 04 with a total shrinkage of 14%, the color being bright red. At cone 1 the total diminution in size was 15%, and the clay brownish red; vitrification came at 2 with 17% shrinkage, and viscosity followed rather soon at cone 4. The tensile strength of the air dried briquettes ranged from 135 to 150 lbs. per square inch.

The clay could hardly be used for vitrified ware, but there is probably no reason why pressed brick should not be made from it. The soluble salts amounted to .7%.

Lansing.—Clippert and Spaulding's brickyard obtains its clay from



CLAY BANK, AND



YARD OF W. LEONARD, KALAMAZOO.

a calcareous glacial deposit, about 2 miles E. of Lansing, on the N. side of the road to the Agricultural College, near the center of the N $\frac{1}{2}$, Sec. 14, T. 4 N., R. 2 W. The clay is curiously located, right in the moraine which passes through Lansing. It is nearly solid clay from the grass roots, though the very top clay is a little stony. At



Fig. 5. Clay bank at Clippert and Spaulding's brickyard near Lansing.

the bottom of the bed, lines of stratification may be seen which are not to be observed in the main mass of the bed. This is shown in Fig. 5. The section is as follows:

Surface....slightly stony.

3 feet....clay, making red brick.

1 foot....clay, making pink brick.

14 feet....clay, making white to buff brick, uniformly calcareous, analyzed.

1 foot....shaly clay, with layers of fine blue sand, red sandy clay, sandy gravel.

This firm make both red and white, handstock, repressed and machine brick, but only white tile, as they have no red brick clay to spare. The cull tiles sell well at half price, and the broken brick



Fig. 6. Clippert and Spaulding's clay bank, Lansing. To the left the clay has been undercut, and a man is preparing to blast it down. To the right may be seen the upper bench of 3 feet of leached clay which makes red brick.

are sold for cistern linings at \$1.00 a load. Different grades of sand are used for molding the red brick, and the white brick, and for mixing, though very little sand is added in mixing. Fig. 6 gives a view of the clay bank, and shows the method of undercutting and blasting down and to the right in the background we can also see the upper bench of red brick clay. The clay does not stand very rapid drying, especially when molded in stiff mud machinery. Its calcareous character is shown by the following composition, which is almost exactly that of the Ionia pottery clay, No. 23:

ANALYSIS 30.

Silica	41.86
Alumina	10.70
Ferric oxide	5.02
Lime	14.33
Magnesia	2.81
Alkalies	2.80
Water	8.00
Carbon dioxide	14.56

Sebewaing.

The surface clay used at the Sebewaing brickyard is a river clay, and is overlain in places by dune sands. The upper two or three feet burns red, while the lower clay in the bank is very calcareous and burns buff. Both clays contain large quantities of lime pebbles, and they are especially numerous in a layer at the juncture of the two kinds of clay. In order to eliminate these from the red burning clay it is treated to a washing process (Plate IV). One puts the clay into a circular sheet iron tank, with water, and the mixture is stirred by arms attached to a vertical shaft. The effect of this stirring process is to get the clay particles in suspension, while the sand and concretions fall to the bottom of the tank. In front of the machine is a screen with half inch meshes, through which the washed and suspended material is discharged into a trough about 50 feet in length. At the end of this trough is another screen with one quarter inch meshes. After passing along this trough most of the sand is dropped, and the clay and water flow out into the settling tanks which have wooden sides and a sand bottom. The water evaporates from these and leaves the washed clay forming a layer about six inches thick in the bottom of the trough. While the clay is settling and drying on the trough the material being discharged from the machine at a later period is conducted into a second or third trough.

It is stated that two men can put enough clay for 16,000 bricks through the machine in one day. This ingenious washing process is a highly important one, and could be utilized at many other localities in the state where there are red burning clays containing lime pebbles or concretions. It furthermore removes the coarse sand from the clay and permits of the production of a much smoother brick, a point which is serious when front brick are to be manufactured.

At the Sebewaing brick works the clays are molded in a Quaker soft mud machine, dried on pallets and burned in scove kilns. While the product is chiefly common bricks still some pressed bricks are made in various shapes and sizes. Their surface is, however, unfortunately roughened by the use of very coarse molding sand.

The lake clays are worked at Badaxe, both red and buff ones being produced. The lower clay bed and the inside of the kiln yield the lighter brick. Soluble salts give some trouble. At Elkton, where a clay from the valley of the Pinnebog is used, we have also a light orange red and a cream colored brick, and limestone pebbles cause some annoyance.

At Croswell, red burning clay is used, while at Minden City both the upper and lower members of the lake clays are employed.

Jackson.

There occurs a bed of potter's clay 5 miles west of Jackson, while at the Adler Brick Co., $3\frac{1}{2}$ miles west, a soft plastic surface clay is employed, which burns red in parts and buff in others. The bricks are molded by the soft mud process and come into competition with the Detroit ones.

The Bennett Tile Co. is located $1\frac{1}{2}$ miles east of town and utilizes a plastic clay, making drain tile and paving brick. They have a clay deposit 7 miles from Jackson, and a narrow gauge road connects it with the works.

At Onondaga the clay is again divisible into a red and a buff burning member. The following is the composition of a clay from G. H. Wolcott's yard, Springport township, Jackson county, from Mineral Resources for 1896, p. 61. Analyzed by Mariner and Hoskins:

ANALYSIS 31.

SiO ₂	52.26
Al ₂ O ₃	22.56
Fe ₂ O ₃	8.15
CaO.....	4.48
Mgo.....	1.32
Water, etc.....	10.56
	<hr/> 99.72

This analysis indicates a more or less direct derivation from a coal measure shale.

Rockland, Ontonagon County.

Wm. Jeff has a deposit of calcareous lake clay near this locality, which, owing to its fineness of grain, easily fusible nature, and cor-



WASHING TANK, SEBEWAING BRICKYARD.



SETTLING TANK, SEBEWAING BRICKYARD.

rect composition, forms a natural glaze. The clay possesses very little plasticity, in fact it acts very much like a fine grained mixture of silica when mixed up with water.

Its composition is as follows:

Analysis No.	32.	33.
SiO ₂	52.92	40.12
Al ₂ O ₃	12.25	11.17
Fe ₂ O ₃	6.45	3.81
CaCO ₃	13.84	11.64
MgCO ₃	3.55	4.17
(NaK) ₂ O.....	3.35	3.61
H ₂ O and organic matter.....	7.14	19.56
	100.00	97.90

1. Analysis by A. N. Clark.

2. Analysis of Rowley Slip Clay, Orton, Ohio, Geol. Sur., VII (1893), p. 105, 12.85% combined, 31.09 free Si O₂; lime as CaO, magnesia as MgO; CO₂ with H₂O; 2.90% K₂O; .10% phosphoric acid.

Compare these analyses of good slip clays with others.

§ 12. Analyses from miscellaneous localities. L.

The following analyses (34 to 39) were also made by Mr. A. N. Clark. They are all from the surface or Quaternary formations. Many of them will be further referred to in the report on marl. They serve, however, very well here to show the calcareous nature and the proportions of lime and magnesia in surface formations.

Analysis.	34.	35.	36.	37.	38.	39.
(Insoluble in HCl) (SiO ₂ and Al ₂ O ₃).....	57.04	75.04	61.10	55.10	65.64	41.94
Alumina and iron.....	4.30	1.90	4.50	6.80	5.35	3.80
Calcium carbonate.....	22.06	14.02	21.00	25.26	16.60	47.23
Magnesium carbonate.....	12.45	6.05	11.76	3.10	9.53	3.79
Organic matter and water.....	4.15	2.99	1.64	9.74	2.88	3.24
	100.00	100.00	100.00	100.00	100.00	100.00

34. Field number A. XII, mostly clay.
 35. " " B. III.
 36. " " XIV A.
 37. " " XIII.
 38. " " XV G.
 39. " " XV, clay evidently near by.

The following partial analysis by Prof. F. S. Kedzie is of a clay from the Muskegon valley, which is also a calcareous surface clay:

ANALYSIS 40.

Silica	38.36
Alumina and iron	22.18
Calcium oxide	13.96
Magnesium oxide	8.19
CO ₂ , etc.	16.45
	<hr/>
	99.14

Finally we cite from the report of the State Geologist for 1892, p. 173, some analyses of Upper Peninsula clays:

Analysis.	41.	42.	43.
Silica.....	51.06	51.60	} 67.85
Alumina.....	21.42	16.43	
Iron oxide.....	7.81	7.27	2.35*
Lime.....	1.98	5.40	14.24
Magnesia.....	3.73	2.88	1.30*
Difference.....	14.06	16.62	14.19*
Sum.....	100.00	100.00	.....

No. 41 is a red clay from Sec. 8, T. 47 N., R. 37 W.; Arthur Uddenburg analyst. It shows the ferruginous character of the iron country clays.

No. 42 is a brown clay from Sec. 6, T. 47 N., R. 36 W.; same analyst and comment.

No. 43. I have calculated from the data: 67.85% insoluble in H. Cl; 1.49% moisture at red heat; lost 12.7% of its weight after an hour at red heat; 25.43% Ca CO₃. Heated to a white heat for ten minutes, it was entirely fused to a dull gray slag; analyst F. F. Sharpless, location Sec. 23, T. 46 N., R. 24 W.

§ 13. Conclusion by Alfred C. Lane.

The account above given of the uses and properties of our Michigan clay will it is hoped be enough to give one an idea for what uses a particular material may be fitted. For those who wish to go further into the subject, the Annual Report of the Director of the Geological Survey, the part on Mineral Resources of the United states, non-metallic products may be commended. For instance in the sixteenth report (1894) there is a paper on the Technology of the Clay Industry, in the seventeenth (1895), on the Clay-working Industry. The Engineering and Mining Journal publishes an annual called Mineral Industry which contains valuable papers. The Clay Worker published in Indianapolis is a trades journal of interest.

Among the recent state publications may be named:

Clay Industries of New York by H. Ries, published by the University of New York, price 30 cents.

Clay deposits and Clay Industries of North Carolina Bull. No. 13 of the State Survey, J. A. Holmes, State Geologist, Chapel Hill, North Carolina.

Preliminary Report on the Clays of Alabama, Bull. No. 6, Geol. Sur. of Alabama.

Ohio clays are treated by E. A. Orton in Vol. III of the Ohio reports.

Missouri shales were treated by H. A. Wheeler in Vol. XI of the Missouri reports.

From these other references may be gleaned.

It is always difficult to tell how far to go in a report on Economic Geology into technology, that is description of manufacturing processes. Many of the reports just cited go more fully into the details in such matters, and any one who really wanted to go into the subject exhaustively would have to go beyond what this report would give in any case. In the same way Prof. Ries omitted details as to the exact methods of chemical analysis and testing, which would be of use only to those who were going to make similar tests, since before making such tests one ought to go to some laboratory where such work is done. There is of course scientific advantage in knowing precisely how things are done, but Dr. Ries has already several times published his methods, and the methods of analysis were those in common use in the State Agricultural College.

Mr. Clark makes the following note:

Some of the alkalies above seem high,—perhaps the clays contain Na as NaCl. The alkalies were usually figured as K_2O . The organic matter and water were sometimes determined by difference which can easily be detected from the exact summation. The iron is all estimated as Fe_2O_3 and in certain cases the FeO has been determined separately. The FeO determinations were made in the absence of a special platinum crucible, and the results are probably low. From two to three analyses were made of each sample except in FeO determinations. The variations were not over 0.2% or if they were, a third analysis was made, except in the case of alkalies where the variation may amount to 0.3%.

No. 36 was also analyzed as a marl would be, by solution in H Cl. which gave less Ca CO₃ showing that some of the lime is in insoluble form as sulphate or silicate.

I have deemed it the truest economy to confine such matters merely to such description as shall make the results intelligible.

I should add that as Dr. Ries wished to spend some time in studying European practice, he left me a free editorial hand. For the articulation, the insertion and arrangement of many of the illustrations and analyses, the descriptions of the Grand Ledge, Lansing and certain other deposits, and minor notes, I am responsible. From Dr. Ries' work I draw the following conclusions:

1. For use in the manufacture of Portland cement, the shales of the Coldwater (Cuyahoga) series are best adapted. The shales of the Michigan series are also good if not too high in soluble salts. Some of the coal measure shales, which are often too gritty, and some of the clays derived from the weathering of these shales or the Devonian black shales may be suitable. Surface deposits of clay of any size are almost without exception either too calcareous and irregular in composition or too gritty to be desirable.

2. Thick deposits of clay are pretty sure to be calcareous and make white brick except at the upper part, where they are leached.

3. The till clays and many others have limestone pebbles which are deleterious and must be washed out.

4. For vitrified ware, paving brick, stoneware etc., we have a considerable range of clays mainly shale clays or clays derived from shale,—in a few cases perhaps river silts.

5. None of the so called fire clays have proved in the highest degree refractory though some of them fuse only with some difficulty. Their field is rather that of stoneware, paving brick, etc., so far as present tests go.

6. Many of the clays beside that of Jeff No. 32 will probably make excellent glazing or slip clays. Probably a considerable variety of these valuable clays await development.

7. Kaolin and other white ware clays have not yet been found.

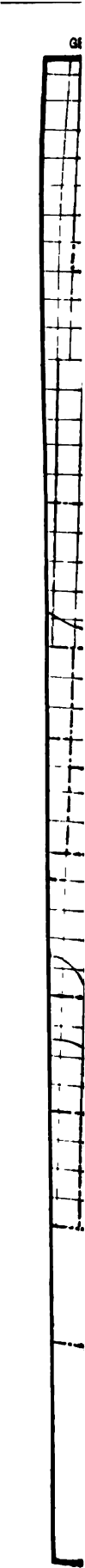
8. Before setting up a clay working plant the clay should be tested by several different methods at some reliable clay working plant. If possible precede this by laboratory tests, but do not try to interpret all the properties of a clay from its chemical analysis alone.

GENERAL INDEX.

A.		Charlevoix	46, 47
Adler Brick Co.....	60	Chemical properties. (See also	
Alabastine Co.....	39, 40	ANALYSES.....	6
Albee Township shale of.....	29	Chester Township, Eaton Co.....	38
Alkalies effect of, in clay.....	6, 7	Clare county.....	55
Alpena Portland Cement Co.....	47	Clark, A. N... 21, 33, 36, 46, 52, 61,	63
Alumina effect of.....	7	Clay	1, 4, 15, 19, 24, 48, 58
Analyses.. 26, 30, 33, 36, 38, 40, 41,		See FIRE CLAY, BRICK	
43, 44, 46, 47, 48, 49, 53, 54,		CLAY.	
55, 56, 59, 60, 61,	62	Clippert Bros., (Detroit).....	49, 50
Arenac Co., shale of.....	39	Clippert & Spaulding, (Lansing)	
B.		49, 56, 57,	58
Badaxe brickyards.....	60	Coal, shales with the. 25, 26, 27, 28,	34
Barium, use of.....	8, 15	Coldwater Cement works.....	3, 41
Bay City shales.....	26, 34, 36	Coldwater shales.. 19, 25, 41, 42, 43,	
Bennett, H., shale of.....	42	44, 45	
Bennett Tile Co.....	60	Color	5, 6
Benton Harbor.....	10	Concretions	9, 14
Berea Grit.....	45	Cones, pyrometric.....	24
Beyne Falls.....	46	Corunna Coal Co.....	27
Branch Co.....	41, 44	Corunna shales.....	26
Brick. See also PAVING BRICK		Courtis, Wm. M.....	49
and FIRE BRICK, FACE		Cramer pyrometric cones.....	22
BRICK and FRONT BRICK		Cream-colored brick, how caused.	6
3, 9, 15, 55,	59	Croswell	60
Brick clay, requirements of.....	4	Crushing strength of brick.....	18
Brick shales, iron in.....	9	Cuyahoga shales.....	19, 43
Brickyards.....	49, 60	D.	
Bronson	41, 43	Davis, Prof. C. A.....	11, 49
Buff color, cause of	6	Detroit.....	10, 48, 49, 50
C.		Devonian shales.....	25, 44, 45
Calcite (lime) effect of, in clay....	14	E.	
Cass River.....	39	Earthenware.....	10, 51
Cement.....	2, 3, 19, 55	East Jordan.....	3, 44, 45, 46
Central Coal Mining Co.....	34, 35	Efflorescence in bricks.....	8
		Escanaba	49

- F.**
- Face brick, manufacture of..... 17
- Feldspar..... 13
- Ferric oxide, effect of..... 6
- See also ANALYSES.
- Fire brick..... 18
- Fire clay..... 4, 13, 18, 21, 25, 30
- Flushing..... 9, 26, 29, 32, 36
- Fluxes..... 7, 10, 14
- Forestville..... 10, 44
- Front brick..... 15, 59
- Fusibility..... 6
- Fusibility, determination of..... 22, 24
- G.**
- Genesee shales..... 25
- Glacial clays..... 48, 57
- Glazes (slip clays)..... 19, 20, 61
- Grand Ledge..... 9, 26, 37
- Grand Rapids..... 39, 40, 41
- Grand Traverse region..... 11, 47
- Geljsbeek, S..... 54
- Gypsum..... 14
- H.**
- Hamilton shale..... 25, 47
- Harrietta..... 20, 48, 53
- Heath, Geo..... 53
- Hersey, Wisconsin..... 1
- Hudson River shale..... 25, 48
- Huron county..... 37, 39, 59, 60
- I.**
- Ionia..... 28, 48, 51
- Iron oxide..... 5, 8, 9
- See also ANALYSES.
- J.**
- Jackson..... 37, 60
- Jeff, Wm..... 60
- K.**
- Kalamazoo..... 48, 56
- Kaolin..... 1, 9, 21, 64
- Kedzie, Prof. F. S..... 41, 61
- Kocher, J. H..... 45
- Koenig, Prof. G. A..... 48
- L.**
- Lane, A. C..... 48, 54, 61, 62
- Lansing..... 48
- Leonard, Wm..... 56
- Lime, effect of..... 5, 6, 10, 14, 48, 51, 53, 59
- carbonate of, see ANALYSES.
- Limonite. (See also IRON OXIDE) 9, 12, 14
- Little Traverse Bay..... 47
- M.**
- Magnesia, effect of..... 6, 11
- carbonate of, see ANALYSES.
- Marcellus shale..... 25, 47
- Marquette..... 49
- Manufacture of brick..... 16, 32, 35, 50, 54, 58, 59
- May, J. F..... 46
- Mica..... 7, 13
- Michigan Coal and Mining Co..... 35
- Michigan series, shales of..... 25, 39
- Michigan Standard Coal Co..... 37
- Mineral Paint..... 19
- Mineral water in brick..... 8
- See also EFFLORESCENCE and SOLUBLE SALTS.
- Minden City..... 48, 60
- Molding of brick..... 16
- Monitor Coal Co..... 36
- Monroe county..... 51
- Muskegon..... 61
- N.**
- Niagara formation..... 48
- Norwood..... 46
- O.**
- Ochreous Paint..... 19
- Onondaga..... 60
- Organic matter. (See also ANALYSES)..... 12
- Orton, E..... 20, 24, 61, 63
- Owosso shale..... 26
- P.**
- Paine's Station..... 55
- Paint..... 19
- Parker, F. L..... 29
- Paving brick..... 3, 4, 17, 18, 27, 28, 29, 32
- Pere Marquette Coal Co..... 34
- Petoskey..... 47
- Plasticity..... 3, 12, 13, 21

Pompeian brick.....	9	Siderite	14
Port Huron.....	49	Silica. (See also QUARTZ and ANALYSES).....	6, 11
Portland cement. See CEMENT.		Slaking.....	2, 3, 21, 25, 53
2, 39, 41, 42, 43,	55	Slip clay.....	19, 60, 64
Potash	7	Soluble Salts.....	7, 25, 56
Potters clay.....	9, 18, 51	Somers, J. H., Coal Co., St. Charles, Mich.....	28
Pressed brick.....	3	Springport.....	60
Productus prattenianus.....	29	Sulphur. (See also PYRITE).....	14
Prospecting for clays.....	24	South Haven.....	49
Powers, Mrs.....	46	Standard Mining Co.....	25, 26, 33, 54
Powers Plaster Co.....	39	Stoneware.....	3, 4, 18
Pyrite.....	9, 14		
Pyrometric cones.....	2		
Q.		T.	
Quartz.....	13	Tabor, Frank A.....	37
Quincy, Branch county.....	9, 41, 42	Terra cotta.....	3, 18
R.		Tensile strength.....	6, 28, 56
Ries, H.....	63, 64	Titanium.....	11
Road material.....	19	Traverse shale.....	25
Rockland.....	60	U.	
Rominger, Carl.....	37, 48	Uddenburg, Arthur.....	62
Bowley slip clay.....	19, 61	Union City.....	41
S.		V.	
Sage & Dethrick.....	51	Van der Heyden, F. H.....	52
St. Charles shale.....	28	Verne Coal Co.....	29
St. Clair shale.....	25, 45, 46	Vitrification	4, 18, 22, 28, 56
St. Ignace.....	48	W.	
Saginaw.....	49, 54	Wait brickyard, Kalamazoo.....	56
Saginaw Coal Co.....	34	Water	12
Saginaw Clay Mfg Co...3, 27, 29,	36	used for washing.....	59
Saginaw shale.....	26	used to work up clay...28,	56
Sand	4, 58, 60	See also ANALYSES.	
Sebewaing.....	26, 37, 48, 59	Weathering....3, 25, 37, 39, 44, 46,	47, 60
Seger's Pyramids.....	22	Wenona Coal Co.....	35, 36
Sewer pipe.....	3, 4, 37	Wheeler, H. A.....	63
Shale.....	1, 15, 18, 19, 25, 48	White Rock shale.....	25, 44
Sharpless, S. P.....	40	Williamston	38
Sharpless, F. F.....	63	Wolcott, G. H.....	60
Sherzer, Prof. W. H.....	51	Wolf brickyard, Detroit.....	49
Shepard, W. H.....	49, 55		
Shrinkage.....	5, 6, 12, 13, 27, 56		



GEOLOGICAL SURVEY OF MICHIGAN

ALFRED C. LANE, STATE GEOLOGIST

VOL. VIII

PART II

COAL

OF

MICHIGAN

ITS MODE OF OCCURRENCE AND QUALITY

BY

ALFRED C. LANE

**ACCOMPANIED BY NINE PLATES AND NINE FIGURES
INCLUDING ONE COLORED MAP**

**PUBLISHED BY AUTHORITY OF THE LAWS OF
MICHIGAN**

**UNDER THE DIRECTION OF
THE BOARD OF GEOLOGICAL SURVEY**

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OFFICE OF THE STATE GEOLOGICAL SURVEY, }
LANSING, MICHIGAN, July 17, 1901. }

To the Honorable, the Board of Geological Survey of Michigan:

{ HON. A. T. BLISS.
{ HON. LINCOLN AVERY.
{ HON. DELOS FALL, *Secretary*.

GENTLEMEN—Herewith I transmit as Part II of Vol. VIII, a report by myself, containing the results of my examination of the coals of the State in a general way.

Although it does not pretend to be exhaustive in its description of the wealth of the State in this particular material it seems to me that it may help give some idea as to the known variations in quality, which is better on the whole than has been reported, may help those who desire to test the quality to do so to best advantage, may give some idea of what has been done, and yet remains to be done in testing, and may save some useless exploration. If I have given especial attention to the probable depth to which it is worth while to test and have depicted the hindrances quite fully it must be remembered that forewarned is forearmed. I have not attempted to trespass on the field of the Commissioner of Mineral Statistics, and the Coal Mine Inspector, Mr. Wm. Atwood, whose valuable reports are made at frequent intervals to the Labor Commissioner, except so far as it has been necessary to use the facts gathered by them in studying problems proper to economic geology.

The records herein given of test borings are reported to us, and I do not guarantee their accuracy. I think that so far as they throw light upon the area and thickness of the coal series as a whole they may be trusted.

Not so much reliance can be placed upon the indications for individual beds, but in any case these can vary much in a few yards.

With great respect I am your obedient servant,

ALFRED C. LANE,
State Geologist.

TABLE OF CONTENTS.

CHAPTER I.

INTRODUCTION.

	Page.
§ 1. Object and history of this report.....	1
§ 2. Comparative development in other states.....	2
§ 3. Authorities for Michigan.....	3
§ 4. Role of the man who wants an option.....	4

CHAPTER II.

ORIGIN OF COAL.

§ 1. From vegetation	6
§ 2. Kuntze's classification of theories of coal formation.....	7
§ 3. Theories of Lesquereux and others.....	10
§ 4. Practical bearing of different theories.....	11
§ 5. Probable mode of formation of Michigan coal.....	13

CHAPTER III.

OCCURRENCE OF COAL.

§ 1. Structure of coal.....	15
§ 2. Varieties of coal	17
§ 3. Slate partings	22
§ 4. Character of the roof.....	23
§ 5. Character of the foot.....	24
§ 6. The Michigan coal basin	25
§ 7. Minor undulations in the coal measures.....	31
§ 8. Variation in coal measures.....	34
§ 9. Low position of the Michigan coal seams.....	41

CHAPTER IV.

ANALYSES AND TESTS OF COAL.

§ 1. Introduction and acknowledgments.....	51
§ 2. Methods of testing	52
§ 3. Sampling	54
§ 4. Determination of moisture	56
§ 5. Determination of ash	57
§ 6. Determination of sulphur.....	59
§ 7. Ultimate analysis	61
§ 8. Proximate Analysis—volatile combustible	62
§ 9. Nature of the volatile combustible or gas.....	63
§ 10. Coke	65
§ 11. Heating power—practical test	66
Lansing Water-Works tests	71
§ 12. Heating power by Calorimeter.....	73

	Page.
Willcox's tests	78
§ 13. Heating power by reducing power. Berthier's method.....	80
§ 14. Heating power computed from ultimate analysis.....	82
§ 15. Heating power computed from proximate analysis.....	85
§ 16. Analyses and samples described.....	89
Tables of analyses	110
§ 17. Conclusions	120

CHAPTER V.

THE EROSION AND DISTURBANCE OF COAL.

§ 1. Recent channels	121
§ 2. Drift filled channels	122
§ 3. Sandstone channels	123
§ 4. Faults or displacements	124
§ 5. Veins	126
a. Clay filled veins, clay seams," "mud seams".....	126
b. Spar veins	126
c. Sulphur partings	127
§ 6. Horsebacks or bars	127

CHAPTER VI.

THE DEVELOPMENT OF COAL.

§ 1. Peculiarities of occurrence as affecting development.....	129
§ 2. Principles to guide explorations	130
§ 3. Methods of testing and developing.....	131
Churn Drills	131
Rotary Drills	132
Sinking Shafts	134
§ 4. Incidental development and information.....	134
Role of the Geological Survey.....	136
§ 5. Promoter and landowner	135
§ 6. Labor value of coal	137
§ 7. Scarcity value of coal	142
§ 8. Value of coal royalties	149
§ 9. Present worth of coal rights and royalties.....	152
Appendix A to Chapter VI.....	154

CHAPTER VII.

DEVELOPMENTS AND BORINGS ARRANGED BY COUNTIES.

Missaukee, Roscommon, Ogemaw	157
Iosco, Lake	158
Osceola, Clare, Gladwin.....	159
Arenac	160
Mecosta, Isabella	161
Midland	162
Bay	166
Huron, Montcalm	172
Gratiot	174
Saginaw	175
Tuscola	191
Sanilac, Kent, Ionia	194
Clinton	195
Shiawassee	197
Genesee	200
Barry, Eaton	201
Ingham	205
Livingston, Calhoun.....	218
Jackson	219

LIST OF ILLUSTRATIONS.

PLATES.

	Page.
I. Geological Map of Coal Basin.....at beginning	64
II. Equivalents in stating or computing heating power of coal, opposite page	76
III. Parr Calorimeter in use.....	96
IV. Upper and Lower Verne seams in the Wenona Coal Mine.....	120
V. View of the flat Saginaw Valley from top of pile of waste rock at Saginaw Mine	140
VI. Trains of lump and slack at Standard mine.....	166
VII. a. Tipple of Michigan Coal Co., St. Charles; b. Tipple of Valley Coal Co., Bay City	168
VIII. Air machine at work on the Verne coals in the Wenona mine.....	At End
IX. Plate of cross-sections.....	
A. Jackson to Bay City, along Michigan Central.	
B. St. Charles to Verne mine.	
C. Clifford to Alma along Pere Marquette R. R.	
D. Amelith shaft to Central Mine.	
E. Amelith Shaft, to Bay Shaft No. 2.	

FIGURES.

1.	Cross-section of Lower Michigan Basin.....	25
2.	Showing shore line oscillations.....	30
3.	Section at Sebewaing shaft	31
4.	Section at Woodville	33
5.	Plan of part of the Porter coal mine.....	48
6.	Diagram, illustrating the connection between the sulphur and iron.....	59
7.	Cross-section of cartridge for Parr Calorimeter.....	74
8.	Cross-section of Parr Calorimeter.....	75
9.	Sketch map of Sebewaing Coal Basin.....	173

ERRATA,

Not Including Mistakes of Capitalization.

Page 28, line 1 from below, read W. F. Ward.

Pages 37, 175, 176. I have carelessly mixed up in my use the names of two prominent Saginaw men. Dr. H. C. Potter was president and superintendent of the East Saginaw Salt Mfg. Co., which put down the first well, but Dr. Geo. A. Lathrop was one of the promoters and kept the record.

Page 39, line 23 from above, for 57 read 5.

Page 43, line 5, for *Discinesca* here and elsewhere read *Orbiculoidea*, which has also been found at the air shaft of the Michigan mine at St. Charles and identified by Mr. Girty as *O. missouriensis*.

Page 54, line 16, before 650 read + instead of ×.

Page 91, line 13 below, read analysis.

Page 105, line 3 from below, read July 23.

Page 166 is misnumbered 66.

Page 168, line 2 from below, strike out comma after Bangor.

Page 185, line 22 read O'Donnell and Spencer Co.

Page 186, line 13 for W.: read E.:

Page 202, line 25, for Milletts read Millett.

CHAPTER I.

INTRODUCTION.

§ 1. Object and history of this report.

This report was prepared in the fall of 1898, at a time of rapid development in the Michigan coal basin, to anticipate and help that development. Its primary object was to give the land owner of Lower Michigan that amount of geological information which would enable him to form an intelligent estimate of the value of his land for coal mining purposes, and to plan intelligently for the economical development thereof. As it could not be published by the Board when prepared, the Board authorized the Michigan Miner to print it serially. The publisher thereof furnished 500 reprints. As these are all gone, and the Board has now ampler means for publication, it is proper for the State to reprint the same in uniform style with the other publications of the Board, for the previous publication cannot be regarded as official.

At the same time the opportunity to bring the report up-to-date has been used, and the discussion of the heating values of our coal has been made far more full, and new formulæ, derived from our analyses, computed for estimating the relative heating value from the proximate as well as the ultimate analysis, and from the reducing power of the coal.

The discussion of the correlation of the coal seams is also extended a good deal and a brief summary of explorations so far as made public is offered.

It was prepared in accordance with that paragraph of the act establishing the Geological Survey that provides for "condensed statements, * * * as often as possible, * * * of important and interesting facts for general circulation," and is deemed advisable and timely, in view of the recently quickened interest in the coal deposits of the Saginaw Valley, and the rapidly increasing production of coal.*

*Revised Laws (1523), Title V, Part V, Chapter 55, Sec. 6.

The hour came when the "inexhaustible supplies of pine" of the Saginaw Valley were practically exhausted. It was no longer necessary to burn slabs to get rid of them. The price of coal imported from Ohio and Pennsylvania was no longer subjected to this healthy competition. This meant that for the continuance of the salt manufacture, and growth and continuance of other industries, a cheap fuel must be found to take the place of slabs. The economic hour struck when the supplies of coal more or less known for fifty years, and outlined by the geologist many years ago, were to be utilized. This development began in 1895.

§ 2. Comparative development in other States.

But, as we shall see, the abundance of cheap wood combined with other and peculiar difficulties to retard the development of the Michigan coal basin in comparison with that of other States. In the intervening years neighboring States have made tenfold the output that we have. Now that we do need to develop our resources, we may have the benefit of their experience if we will, and we shall be foolish if we do not avail ourselves of it. For there are certain rules as to the way coal occurs that have proven so widely true, that they may be expected generally to hold true in the future, though, as for all rules, we may expect some exceptions. In thus drawing on the experience of other regions I shall use especially States lying near by in the Mississippi Valley, and recently studied, examined and reported upon, to wit, Ohio, Missouri, Iowa and Indiana. I shall lay down a rule which I take to be applicable to the occurrence of coal in Michigan, shall state briefly some of the facts that indicate that the rule applies in this State, and then cite the authorities that declare the rule to hold true elsewhere also.*

*For Iowa, Iowa Geological Survey, Vol. II, by Chas. Rollin Keyes, Des Moines, 1894, hereafter cited as Keyes, Iowa, 1894; also Vol. VII, Annual Report for 1896, with accompanying papers, Des Moines, 1897, especially pp. 263-413, "Geology of Polk County," by H. F. Bain, cited as Bain, Iowa, 1897; also an article by H. F. Bain in the Journal of Geology, published by the University of Chicago, Vol. III, p. 646.

For Ohio, of the Reports of the Geological Survey, Columbus, Ohio, especially, Vol. V, Economic Geology, pp. 1-300 and 773-1083, cited as Orton, Ohio, 1884; also Vol. VI, Economic Geology, Columbus, 1888, cited as Orton, Ohio, 1888; also Vol. VII, Economic Geology, Norwalk, 1893, pp. 255-280, cited as Orton, Ohio, 1893.

For Missouri, Preliminary Report on the coal deposits of Missouri, by A. Winslow, Geological Survey of Missouri, Jefferson City, 1891, cited as Winslow, Mo., 1891. In this work on p. 31 is a useful list of further references, and Mr. Winslow published much the same general account in the Bulletin of the Geological Society of America, Vol. III, 1892; pp. 109-121, cited as Winslow, 1892.

For Indiana, the 23d Annual Report of the State Geologist, 1898, is a very detailed work.

Both Keyes and Winslow derived much from the older reports of the Pennsylvania Second Geological Survey, under J. P. Lesley, which has made very voluminous publications, and Pennsylvania may be taken as the type State of the Union for the Carboniferous series.

Of particular interest and instruction for us is that by J. J. Stevenson, KKK, Report of Progress in the Fayette and Westmoreland District of the bituminous coal fields of Western Pennsylvania, Part II, the Ligonier Valley, especially

§ 3. Authorities for Michigan.

The foot-note to the previous section has given some authorities outside the State. As regards the Michigan basin, we have the State reports, to wit: The reports of the State Geologist, Douglass Houghton, and his assistants, Bela Hubbard and C. C. Douglass, in 1839, 1840, 1841; the Biennial Report by State Geologist A. Winchell, in 1861; the report by Carl Rominger in 1876 (III of the present series); the report by Wright & Lane in 1895 (Vol. V of the same series); also the reports of the Commissioners of Mineral Statistics (those by C. D. Lawton, 1881-1888 particularly valuable).

Vol. VII, Part II (Huron county), contains a report on the area around Sebewaing. An early private paper and account of practical exploration near Lansing and along the Cedar River, chiefly, is by R. B. Lansing, "Exposition Concerning the Mineral Coal of Michigan," Detroit, 1854. In the Twelfth Annual Report of the Saginaw Board of Trade there are also some analyses of Michigan coal.

Concerning the recent developments we have two pamphlets issued by Mr. C. B. Schaefer. But I have had access to a large amount of unpublished matter. I may note especially an unpublished report by A. Winchell for the Detroit, Grand Rapids & Indiana R. R. on the prospects for coal along their line; a report by S. G. Higgins to the Saginaw Board of Trade on explorations south of that city; most of the original coal mine maps of the Jackson mines, which with other valuable and instructive data I owe to John Holcroft, Esq. Finally, I have also notes of personal visits among other points to Sebewaing, Corunna, Jackson, Rifle River, Owosso, Grand Ledge, Williamston, the valley of the Thornapple, the results of systematic studies and surveys of Huron, Tuscola, Saginaw and Bay counties, and a very large amount of data concerning

Chapter II, p. 233. This State also publishes the reports containing Lesquereux's most thorough work on the coal plants. The Pennsylvania reports are cited by capital letters, KKK, P, etc. On the same region, but extending farther south, is Bulletin No. 65 of the U. S. Geological Survey (Washington, 1890), by I. C. White, price 20 cents.

In the Bulletin of the Geological Society of America, Vol. IX, pp. 35-58, is an interesting paper by W. S. Gresley on "Clay veins vertically intersecting coal measures." On the statistics and business of coal, W. J. Nicoll's 'Story of American Coal,' Philadelphia, 1897, and the annual volumes of Mineral Industry, issued by the Engineering and Mining Journal, and the parts devoted to statistics of the Annual Reports of the U. S. Geological Survey may be consulted. On methods of coal analysis and determination see Chapter IV.

The reports of the various State Geological Surveys may be obtained upon application to them at the capital cities above mentioned, and separate reprints of papers published in the Bulletin of the Geological Society of America may be obtained from Prof. H. L. Fairchild, Secretary of the Society, Rochester, New York.

In the Twentieth Annual Report of the U. S. Geological Survey, 1898-99, Part II.—General Geology and Paleontology, there is a paper on the Stratigraphic succession of the Fossil Floras of the Pottsville Formation, by David White, which is of interest.

borings in various parts of the State which have been collected by the State Survey during the past few years, some of which were collected for a report on the water resources of Lower Michigan, published as Nos. 30 and 31 of the Water Supply and Irrigation papers of the U. S. Geological Survey. I am also deeply indebted to most of the mine managers and many drillers and others for information. But I *have not attempted to give all the facts* upon which the *general* rules summed up in this short report are based, but merely enough to illustrate and make clear their application. Most of the material must, however, be gathered from the daily press or unpublished sources. Of especial interest is the Saginaw Evening News of Saturday, July 23, 1898, "Board of Trade and Coal Development edition."

The statistics are given in the reports of the Labor Commissioner and the Commissioner of Mineral Statistics.

§ 4. Role of the man who wants an option.

The problem of estimating the mineral value of lands, is not easy, and one is quite as likely to over-estimate as to under-estimate it, as the human mind tends to exaggerate the unknown. The following tale has a familiar sound to me: "There was a fellow around here a while ago, who wanted an option on my land, and offered to pay a little cash for it, but I was in no pressing need of money, and I thought if there was anything to be made I might as well make it myself, so that I would wait and see what his explorations showed up. But that was the last I heard of him, and now I am sorry I did not take his money." Compare the fate of coal explorations around Saginaw as recorded in the Standish Independent, December 2, 1898.

There is a tale told of Dr. Rominger, which, whether true or not, illustrates the point, that in the days of the coal excitement on Rifle River along in the '70s he was approached by a homesteader, who wanted to know what his land was worth. "Well," said Dr. Rominger, "Your land is pretty sandy and not very good for farming; if you get \$10 an acre you had better take it."

"Ten dollars an acre! Why a man has offered me forty already!"

"Well, didn't you take it?"

"No."

"Well, then, there were two fools instead of one."

The role of the "man who wanted the option," whom for short we

call the promoter, is often misunderstood even by himself. He is looked upon as one who has occult knowledge and wishes to take advantage of people's ignorance to beat them out of property, the value of which they do not recognize. This of course he may sometimes do, just as any merchant may over-reach, but he has a legitimate and necessary business, and a useful part to play, even though the land owners knew all there was to be known, or though he told them all that he guessed or knew, as to the present or prospective value of their property. Incidentally we shall show what this legitimate business is.*

*See Chapter VI, § 5.

CHAPTER II.

THE ORIGIN OF COAL.

§ 1. From vegetation.

To understand the occurrence of coal, and from our partial knowledge to predict how it will occur, requires some knowledge of its formation.

Without going into the details of controversies on minor points, we may say that such coal as we have in Michigan is universally believed to have been formed from the deposits of decaying vegetation. Wood and peat have been turned into coal, both by accident and by intentional experiments. That the coal of our coal measures was thus formed is shown, not only by the stems and leaves that are often preserved in connection, especially in the shales above and below, but by a woody texture which may often be brought out even in comparatively massive and uniform beds of coal, by sections of it cut so thin as to be translucent like veneers. For the nature of the vegetation one must consult more extensive works, like Lesquereux's *Coal Flora*, published by the Pennsylvania State Geological Survey (p. 635). All the specimens sent to Lesquereux by Rominger were the floating stems known as *Stigmaria (ficoides) verrucosa*. Fragments of forms known as *Calamites*, *Lepidodendron*, and *Sigillaria*, which are plants allied to the scour-rushes, club mosses and ground pine. Ferns are comparatively rare. Rominger who was a careful observer reported them only for Sixmile Creek, north of Owosso. Recent openings have, however, given us a better chance, and they are now known from Grand Ledge, the Standard Mine, Saginaw, and other points.*

Recent investigations have shown that the spores of such plants (like lycopodium powder or pollen) have helped to form quite a part of the coal, especially cannel coal. Seaweed and the herbs and

*Page 44.

plants of dry climates, like the cactus, do not furnish much coal-forming woody fibre.*

When we come to ask how much vegetable matter is required to produce coal, having due regard to the facts that coal is about twice as heavy as wood, and that wood contains much beside carbon, and that some part even of the carbon escapes in the process of conversion to coal, we find the shrinkage estimated at anywhere from $1\div 10$ to $1\div 30$.†

We can obtain some idea of the compression by noting how thin stems have become, which are turned to solid bright coal. The breadth will be somewhere between the diameter and half the circumference of the original stem. In a stem turned to solid coal which I recently noticed, the thickness was $1\div 16$ of an inch, while the breadth was $1\frac{1}{2}$ inches, indicating a compression of $1\div 18$ to $1\div 28$.

Thus to account for a bed of coal five feet thick we must account for the formation of a bed of vegetable matter over 60 feet thick, intermixed with considerably less than 10 per cent of sediment. This is not an extraordinary requirement, for peat bogs have been found 200 feet thick, with no bottom even then, and even in Michigan I have reports of a case where a fifteen-foot pole has failed to find the bottom of the soft semi-fluid muck under the comparatively firm top of such a bog.

§ 2. Kuntze's classification of theories of coal formation.

Dr. Otto Kuntze in a recent work,‡ has given the most exhaustive and recent schedule of the ways in which the deposits of vegetable matter for the formation of coal may be formed. I translate his summary freely. His terminology is rather cumbersome. I do not recommend it.

I. Local or indigenous (Autochthonous) deposits: in which the deposition of the coal forming substance took place directly on the ground upon which the vegetation grew, without the intervention of water to spread it out in layers; with, interlaminated

*Otto Kuntze *Geogenetische Beltraege*, Leipzig, 1895, 1895, p. 63.

†Englehardt, cited in Kuntze's *Geogenetische Beltraege*, p. 65, gives 30÷788; Keyes Iowa, 1892, p. 48, says that 4.5 feet of coal are equivalent to 30 ft. of wood, or 4 ft. coal= 60 ft. peat; Bain, *Journal of Geology*, Vol. III, p. 648, supposes a contraction of $1\div 10$ or $1\div 16$; Lesquereux (*Pennsylvania Report P*, p. 610) says that the annual layers of peat are about 1 inch thick near the surface, at 10 to 12 feet below are compressed and consolidated so as to be but $1\div 10$ of an inch, while in coal they are but $1\div 20$ of an inch thick, according to which it would take 240 years, or, if the coal plants grew twice as fast as peat, 120 years to form a foot of coal.

Soilas, *Science N. S.* Vol. XII, p. 308, following A. Geikie, estimates that peat bogs may have grown 6 feet per century, and coal 1 foot per century.

‡*Geogenetische Beltraege*.

layers or rather streaks of sedimentary coal formed from leaves as an unimportant exception.

Under this head we have the following subdivisions:

1a. Subtropical or tropical layers of lignite, i. e., brown coal, formed from forest clad swamps, without *Sphagnum*.

1b. Recent peat formations, in cooler regions, formed by *Sphagnum*, i. e., floating swamp mosses.

1c. Mixed formations, from swamps only partly overgrown with trees and shrubs (like our tamarack swamps or the southern cypress swamps), which are from time to time flooded with irregular deposits of sediment which produce lenticular laminæ that run out in all directions; this is because the growth of vegetation was continuous, and the repeated floods irregular and local, the detritus being generally drifted in different spots each time.

1d. Littoral swamps with irregular marine or brackish water admixtures, which may be explained by local alterations of the delta (formation of bars and tidal action) without catastrophic marine inundations.

1e. Leaf coal, formed by the falling leaves and twigs of trees that grow on the banks of stagnant waters, which sink on the spot, are carbonized by the humic acids, and somewhat assorted and leveled off by the water. To this method of formation Kuntze attributes only coal streaks,—so subordinate components of the country rock or the coal (like the present formations in forest clad marshes) that they may merely smut, as it were, the principal mass of the coal or the country rock.

II. Derived or Transported (Allochthonous) deposits: those deposited irregularly in coarse fragments at a distance from the point where the vegetation grew. Only powdery detritus is deposited in laminæ if it floated away.

2a. Driftwood or other wood buried by accident (from trees or forests overturned or sunken with the soil) may form almost negligibly small components of the rocks or mere streaks of coal, but not layers of coal.

2b. Displaced coal beds, transported for example by ice action. The fragments of coal often found in the gravel and till, would be classed under this head. They are especially common in Michigan, in the sands and gravels, and especially when struck in wells often excite hopes which can only be disappointed. No coal without a

good roof, and no coal that occurs in the surface clays, till, sand, or gravels, has any commercial value.

2c. Sedimentary peat: The very finest peat detritus is in exceptional cases somewhat washed away and may help to form,—

c'. Lake peat, with few or even no clay lamellæ, which are often visible only with a microscope.

c''. "Papier torf," i. e., bituminous clay with infusorial earth charged with silicious diatoms.

c''' "Blaetter kohle," foliated coal, i. e., a marly clay with a little sedimentary peat mixed.

III. Marine (Pelagochthonous) deposits: Coarse waterlogged vegetable matter is deposited directly beneath the vegetation (which grows on the surface of the water) in sedimentary layers; a by-product is the powdery detritus which is often washed out of the coal-forming substance and deposited apart by itself as anthracite. (This theory of Kuntze as to the nature of anthracite is not generally accepted.)

3a. The normal Carboniferous coal beds (*paralische*) are, Kuntze thinks, composed of the remains of floating forests, which grew out on the open sea. Such beds, he says, show no remains of trees that root in the mud, except in narrow districts that are near the margin, but are composed only of sedimentary laminated coal extending often over vast stretches, and in hundreds of beds which alternate with strata of inorganic material, each bed remaining nearly constant in thickness or running out in one direction. To this group he assigns the "*paralische*" coal fields of Naumann, which are most finely developed in North America and China, in which the many thin coal beds alternate with much more heavy strata of sediment and are not infrequently replaced with marine limestone. There are, however, also very thick as well as widespread pelagic coal fields. This is Kuntze's pet theory as to origin of coal, for which he argues at such length that reference must be made to the original article.

3b. Coal beds formed in the arms of the sea; more limited but in part very thick layers of laminated coal. Frequently on the side toward the deep ocean the coal layers wedge out into many separate layers, interdigitating with marine beds. Beside the remains of the floating marine forests are also abundant remains of trees that root in the mud. This group is most beautifully developed in France.

Here belong in part the marginal ("limnische") coal basins of Naumann, who did not yet at that time divide the black coals into Tertiary coals without and Carboniferous coals with minute lamination. The Carboniferous coals are characterized as themselves marine formations by their frequent transition into marine limestone, and this also applies to the marine basin formations. The expression limnic, Kuntze would retain only for continental basins.

3c. Amorphous anthracite; consisting of the very finest detritus, with microscopic layers of clay, washed away and deposited by itself, from the Silurian to the Upper Carboniferous, in all regions, generally forming irregular layers. By anthracite in this sense is understood only the kinds most rich in carbon, which show no microscopic lamination, and "faser" or splint coal, stone coal, "staub" or small coal, and coking anthracite are excluded. Such amorphous and yet sedimentary anthracite, which, however, generally encloses "faser kohle," are, he thinks, only washed out of some other magma. Whether there are silurian anthracites which have been formed out of herbaceous vegetation only, Kuntze leaves an open question.

Really, however, to the cannel coals and certain laminæ in every bituminous coal this method of formation could better be assigned than to anthracite, which differs from bituminous coal in secondary alteration more than in anything else.

Of the various methods 1b and d and 3b and c seem most important in considering the origin of our Michigan coals.

§ 3. Theories of Lesquereux and others.

Lesquereux was by far the ablest upholder of the theory that the coal was formed practically like the peat of bogs, and the Annual Report of the Pennsylvania Geological Survey in 1885* gives the latest account of his views, and at the same time of Kuntze's theory (3a), which he considers of all others the most able rival to his own. But one of the objections which he urges to Kuntze's theory, the conformability of the coal to the underlying beds if we may believe Winslow,† will not hold. The presence of underlying fire-clay beds, which is another argument which he uses against Kuntze's theory, is not universally true, and even when true would not, as it seems to me, exclude Kuntze's theory. One of the chief objections to Kuntze's theory in my mind is that so frequently heavy sandstones and other

*Pages 94, 114; see also the final report 1895, pp. 1929-1930.

†Winslow, Mo., 1891, Chap. 1.

beds that appear to be formed along shore occur in the coal formation, that one can hardly think it formed far from shore. Moreover, there is no doubt that the tendency of recent investigation is to limit the extent of the continuous coal beds, in the Mississippi region at least, far more than either Kuntze or Lesquereux realized.* But as Lesquereux lays great stress upon the capacity of bogs to form floating superficial mats of vegetation, and speaks of the coal plants "Borne upon a solidly compact raft of creeping *Stigmara*," and since he and Kuntze both agree in regarding the *Stigmara*, contrary to a current view,† as horizontal stems, like those of the ground pine, but in water and with water leaves, serving to float (freely like the bladderwort, *Utricularia*), various kinds of vertical stems, their theories are really not so far apart. Both Kuntze and Lesquereux agree in what is a matter of common observation, that very little matter is carried away by rivers out of swamps, and with that the observation of every one will agree.

The wisest policy is to consider all possible methods of formation until the circumstances of each coal seam indicate the one or the other origin for it.

§ 4. Practical bearing of different theories.

And yet as we find one method of formation more and more indicated we shall look to it more and more as the method of formation in cases when it is important for us to know in advance how a seam was formed. For these matters, interesting as they are as pure speculation, and fascinating as it may be to reconstruct the coal depositing forests in our fancy, have also a practical importance.

For instance, the 147-foot coal of St. Charles is much farther above the Marshall sandstone than the 80 to 120-foot coal at Sebewaing. If Kuntze's theory is applicable to the Sebewaing coal bed, we are likely to find it everywhere at nearly a uniform distance above the Marshall sandstone. If, on the other hand, the Sebewaing coal was formed merely as a marginal bog, we need not expect to find it in strata which formed at the same time near the center of the basin. Or if it does extend out that far it may be above coal seams which were formed earlier at a time when the coal basin had not settled so far. A coal seam twenty feet above the base of the coal formation at the center of the basin would be earlier formed and geologically older than one an equal distance above the base of the formation

*See below, pp. 31 to 41, also the Indiana report.

†Report P. p. 602.

at the margin. If Kuntze's theory applies we may expect to find the Sebewaing coal, which is about 142 feet above the Marshall sandstone, far below the St. Charles 147-foot coal, which must be over 500 feet above the Marshall.

Chemically, however, the Sebewaing and other coals of the margin are more like the upper seams of the center. The Sebewaing resembles the Lower Verne coal which can almost continuously be traced to the seam at 100 to 150* feet around St. Charles, while the deep seam at St. Charles, between 180 and 200 feet down is chemically like the Saginaw coal, and drilling indicates that it is nearly continuous. There are still lower coal horizons than this, so that if Kuntze's theory is applicable here, a correlation of the Sebewaing and Jackson seams with those of the Verne mine and the shallow seams of Bay City would be entirely inadmissible. In the one case we should expect to find the Sebewaing coal below the St. Charles upper coal; in the other we should not.

Keyes supposes the Iowa coal to have been formed in part, and mainly in marine swamps, but in part also in fresh water lakes, and in estuaries where driftwood might accumulate. Orton† ascribes a marine origin to many of the lower coals, and feels confident that the Sharon coal, to which, as we shall see, some of our coals are probably equivalent, was formed on the spot, in marginal swamps with the sea nearby, while the Freeport coals he takes to be fresh water coals.

David White assumes that the conditions of formation of the Pottsville formation in Pennsylvania were "a continuous broad base-level, coastal-plain shore and currents both strong and varying, so uniform and so rapid as compared with the geologic time required for the sedimentation of the terraces that the similar associations of identical species occurring at different points along the coast are to be regarded as approximately contemporaneous."† "Brief periods of stability or even slight reactive uplifts, in conjunction with bar-forming currents may have assisted in producing lagoons, coastal swamps or other conditions suited either to the accumulation of vegetable matter or to the deposition of thin beds of argillaceous matter." Thus we see that geologists of adjacent States are not inclined to ascribe to all their coals exactly the same conditions of formation.

*See Pl. IX.

†Pages 812, 822.

§ 5. Probable formation of Michigan coal.

But on the whole the conception of the way our Michigan coal formed which it seems to me best satisfies the conditions of its occurrence is somewhat as follows: The center of Lower Michigan was occupied by an arm of the sea, or more likely, an independent sea, like the Black Sea, opening to the southwest. The land had been higher (during later Kaskaskia time and while the Parma sandstone was depositing) just previous to the formation of the Coal Measures, and was settling slightly so that the river valleys were flooded like the shore of Western Michigan and Monroe county at the present day. The inlets, which are characteristic of a settling shore and represent the flooded lower parts of river valleys are often cut off by sand bars and dunes from the main sheet of water. Such are the lakes upon which Benton Harbor, Grand Haven, Muskegon, and Manistee are built. Out from the margin in the bays and inlets may have crept great floating bogs or mats of vegetation, tropical, closely matted, slowly decaying and weighed down by the ever-increasing growth above. Occasionally it became overburdened and sank bodily,—an accident which happens nowadays to floating peat bogs overgrown with forest,—or the water-logged part dropped bit by bit to the bottom. This green carpet over the water kept pushing farther and farther out and was somewhat like the ice forming around the edge of a lake in winter. Like that, too, an occasional storm would drive it back in winrows and perhaps swamp it. This floating forest shed abundant spores and pollen-like powder, which were blown and drifted all over the sea, helping to make a carbonaceous mud, which later became black shale, cannel coal, or bituminous limestone.

The rivers contributed their share toward filling up the sound, which may have been shallow, like Saginaw Bay, where the rushes wave from the water thousands of yards from the shore. There were probably minor oscillations between sea and shore, but on the whole for a while the land sank relatively and the sea overlapped unconformably on the land. Then the sea level remained fairly constant until the sea was largely filled up. Then the land rose and erosion began. But that we will consider later. I beg the reader now to hold this conception culled from the various theories in his mind, and as we pass to consider the actual facts as to the way in which Michigan coal occurs, to compare it with them, for it is by the facts that it and every other theory must be judged.

There are one or two of Kuntze's arguments, however, directly applicable to our Michigan basin, which we shall not have occasion to bring in later, and may glance at now.

In the first place, we may naturally account for the salty water which saturates the formation by supposing that the rocks were originally laid down in water at least brackish. In the same way the sulphates which are characteristic of the waters of the coal series may be derived from the sulphate of lime in the sea water, either directly or through sulphides which were themselves derived from the decomposition of Ca SO_4 by organic matter, the S, or rather H_2S , set free picking up iron from bog iron ore.

If this is the origin of the sulphide of iron which is so constantly associated with the coal we can understand why there is practically no excess of sulphur, but just enough to combine with all the iron. That is what the chemist would expect if the iron and organic matter precipitated the sulphur from an excess of sulphated waters.

It is, however, conceivable that the salt and sulphates were derived by percolation from beds below, or by erosion of these beds, around the margin of the sea.

We may also note that our former State Geologist Dr. Rominger agrees with Kuntze in thinking that the *Stigmaria* were creeping stems (rhizomes). "Some of them," says Rominger,* "are found covered with leaves radiating in all directions—as if the apex of a branch had been immersed in the liquid clay paste without any disturbance of the expanded leaves. The leaves are long and band-like, flat at the outer end, sub-cylindrical, clavate and connected at the basal ends with the stems."

*Vol. III, Part I, p. 127. See also Scott's *Studies in Fossil Botany*, reviewed in *Science*, March 8, 1901. He considers them rhizophores.

CHAPTER III.

OCCURRENCE OF COAL.

§ 1. Structure of coal.

If we examine a piece of our Michigan coal we see that it has a very distinct cleavage in one direction, though the cleavage is along warped or irregular surfaces, upon which frequently appear fragments of vegetation, apparently bits of rushes turned to coal. This cleavage runs parallel to the bedding and in the mine lies usually nearly horizontal. At right angles to this cleavage, standing nearly vertical in the mine, the coal is also divided by partings, known as joint planes or the cleat of the coal. The better developed set is generally called the face of the coal and the other the butt, and when they are both well marked and at right angles or nearly so, as is often the case, the coal is cut up by them into blocks or rough cubes, and is called "cubical coal," or "block coal." Where they are well developed it is easier to get the coal out in large masses, and in laying out a mine the endeavor is so to lay it out that the working faces will run parallel to the face of the coal. A charge of powder will then blow down the largest amount of coal from the under cut face instead of wedge-shaped pieces, as it would if the cleat of the coal ran diagonal to the working front. When the face parting is much the better developed the term cleat is sometimes applied to this alone, but sometimes the difference in the two partings is very slight, and their naming a matter of custom and convenience, and sometimes the cleat is very poorly developed.

These partings cannot be put through anywhere in the coal, but occur at certain intervals. They are often smoother than the bedding planes, and not infrequently spangled with bright brassy coatings of sulphide of iron. This is a deleterious ingredient, but the spangles on these planes make a great deal more show than they do harm, and do not introduce half the amount of sulphur that is introduced in little obscure, hardly observable, apparently insig-

nificant streaks parallel to the bedding. The sulphur is, as Mr. Hilton has shown (pp. 59 and 99), almost entirely in the shape of sulphide of iron, but the water of the region is strong of sulphate of lime, in which form the sulphur is by no means so injurious. I have seen little crystals of sulphate of lime (gypsum) on the faces of the coal. The analyses of Table A, Chapter VI seem to show that the sulphur naturally present as sulphates is less than one-third of one per cent.

Sometimes, too, the cleat faces are covered with thin white coatings of carbonate of lime, "spar" or fibrous gypsum.

If we look at these joint planes carefully we shall find on their surface the direction of cleavage or bedding marked by a series of lines where it cuts across thin laminae. Some of these laminae are bright and pitchy in lustre (German "glanz-kohl"), and are an essential constituent of cubical or block coals. Other laminae are dull in lustre, soft black, have more the structure of charcoal, and have indeed the woody structure better preserved. These laminae are known as fossil charcoal, mineral charcoal, fibrous coal (German "faserkohle," in Great Britain "mother of coal"). Occasionally we may see dull, slightly brassy heavy streaks of sulphide of iron. Even when it is so smeared and sooted with intermixed coal as to appear black, such sulphide of iron may still be detected by the extra weight, and is sometimes known as black jack. But there is another black jack which is a sulphide of zinc, that I have seen in nodules in shales above the coal. Black jack is a term also occasionally applied to black slate, "jack" implying in a general way something of which to be rid. The iron sulphide is so much heavier than the coal that the coal may easily be washed free from a good deal of it.* A coal with much sulphur will, if left in a damp place, soon begin to split and become covered with delicate white needles which have a nasty inky taste, being made of vitriol (sulphate of iron, melanterite).

If our Michigan coal is put on top of a hot stove, it will yield after the steam is first driven off an aromatic smoke, long before it catches fire. This may be burnt as a gas. The matter thus driven off is the volatile combustible, a so called bituminous matter (it is not really chemically bitumen), which is present in all coking and

*See article in the Trans. Am. Soc. of Mech. Eng. Vol. XVIII, No. 708, Dec. 1896, on "The Washing of Bituminous coal by the Luhrig process," by J. V. Schaefer, Chicago, Ill. The Campbell washer is also much used.

gas coals. Michigan coal is to be classed as a bituminous cubical or block coal, inclining to be a gas coal and a coking coal, though these latter two qualities differ in different seams.

As all the coal of Michigan is probably not of the same quality it may be well to describe the different kinds of coal.

§ 2. Varieties of coal.

We arrange the varieties of coal, so as to treat first those which have the most carbon in a fixed* condition, i. e., in such a state as to be burned off only at a red heat or higher, and not so combined as to be evaporated away in the aromatic smoke at gentler heats.

Graphite, the last stage of alteration of vegetable matter, is pure carbon except for the mineral matter. An impure graphite is found and mined in the Upper Peninsula of Michigan near L'Anse and is a frequent constituent of the Upper Huronian Slates.

Anthracite, hard, "stone coal," with but 3 to 10 per cent of volatile matter, as the analyses below given indicate. Almost all the

COMPARATIVE ANALYSES OF DIFFERENT KINDS OF COAL.

	Fixed carbon.	Volatile carbon.	Water.	Sulphur.	Ash.
Anthracite, Lehigh, av. of 20 analyses	: 89.25	: 9.86	:	:	: 4.20
Anthracite, Schuylkill, av.	: 89.068	: 2.494	: 1.457	: 0.252	: 6.701
Semi-anthracite, Lykens Valley, Wisconsin, av. of 30 analyses.....	: 88.30	: 10.42	:	:	: 6.11
Semi-bituminous, Tioga Co.	: 87.791	: 20.506	: 1.65	: 1.257	: 8.352
Bituminous, Maessillon, Ohio.....	: 81.40	: 32.90	: 4.10	: 1.07	: 1.60
Bituminous, Maessillon, Ohio.....	: 53.5	: 37.00	: 5.5	: 1.1	: 4.00
Bituminous, Conneltsville, Pa., coking:	: 69.61	: 20.107	: 1.25	: 0.784	: 8.33
Bituminous, Butler Co., Pa.	: 48.967	: 39.883	: 1.91	: 1.968	: 7.222
Bituminous gas coals, Clarksburg, W. Va.	: 41.60	: 56.74	:	:	: 1.00
Peytons, cannel, W. Va.	: 41.00	: 46.00	:	:	: 13.00
Clarksburg, cannel.	: 45.48	: 49.21	:	:	: 5.35
Coshocton Co. Ohio, cannel.	: 44.50	: 44.40	: 1.50	: 1.72	: 9.60
Lignite, Golden, Col.	: 47.58	: 34.75	: 13.67	:	: 4.00

anthracite used in the State comes from the Lehigh Valley in Pennsylvania, and in spite of newspaper reports, none has been nor is likely to be found in Michigan, at any rate in commercial quantities. Some of the so called graphite of L'Anse and the associated black slates is anthracitic in nature.

Semi-anthracite and *semi-bituminous* coal, has 10 per cent to 18 per cent volatile matter; is laminated, with bituminous layers and thin partings of cannel coal, or mineral charcoal; makes a dense coke especially good for blacksmith's work; has not yet been found in Michigan and is not likely to be except in subordinate quantity.

*See Chapter IV, p. 63.

The Pocahontas coal stands on the line between semi-bituminous and bituminous. See also analyses in Chapter IV.

Bituminous coal, with over 18 per cent volatile matter, of which about $4\frac{1}{2}$ is hydrogen combined with carbon. This is the family of coal to which Michigan coals belong, and is subdivided into:

Steam coal (*block*, or cubical, when it breaks readily into rectangular pieces, *splint*, *furnace*, or *soft coal*). Open burning, with thin layers of cannel coal or mineral charcoal alternating with pitchy lustrous layers, melting and sometimes caking, but not compacting into coke. It may contain less bituminous matter than coking coal, but not always, and the line between these coals and coking coals is rather vague, and the connection with the composition of the coking property, not clearly made out. In fact, organic substances of exactly the same ultimate composition will, on being burnt, the one coke, and the other not, and a coal which will coke when first taken from the mine, may cease to do so when exposed to the air for a few days. Sometimes pulverization aids coking. Exposure to air deteriorates bituminous coal.*

Coking (*cementing*, or *caking*) coal, is quite high in bituminous matter. The pitchy layers are broad, and separate thin dull laminæ which are often broken. They are low in water, and may have from one-half per cent to 15 per cent ash. For the coke to be of most value it should be clear, bright, hard, open textured, with little sulphur. The best and simplest test of the coking capacity of a coal is to try it.†

Gas coal is usually a coking coal, but may be a cannel coal. It should be high in volatile matter and free from sulphur. All Michigan coal seems to run high in volatile matter.

Cannel coal is a very bituminous coal with a considerable amount of ash. One essential feature is the structure which is more compact than that of ordinary coal, so that it has not the alternation of light and dark laminæ. Usually it is less pitchy and brilliant, though some varieties (jet) will take a high polish, but it is always uniform, and is a good gas coal. It is also a favorite coal for household use, as the large amount of ash, acting as a wick, makes it burn

*Orton, Ohio, 1893, p. 268; also Hale, R. S. and Williams, H. J. Am. Soc. of Mech. Engineers, Vol. XX (Dec. 1893), No. 798.

†Sulphur seems rather to aid coking, but cannot be over $1\frac{1}{2}$ in coke for iron furnaces and anyway is not a desirable ingredient. Generally it can be largely driven off in coking. Moisture does not aid coking. Some coals will coke when ground fine,—disintegrated, which will not do so when heated in coarse lumps. There is an important article on by-product coke ovens in Mineral Industry for 1895.

with less smoke. Hence its name cannel, i. e., candle. It "represents the carbonaceous mud from the surrounding swamps which furnished the cubical coal," and passes into black shale. In its make-up lycopod spores and pollen-like matter play a large part. The Michigan coals seem to lean generally toward cannel coal. It is often difficult to know where to draw the line, as I have elsewhere remarked* between cannel coal and black shale on the one hand, and common bituminous coal on the other.

Black shale while it does not show the layering of ordinary bituminous coal has a very well marked cleavage parallel to the bedding. The relatively weak development of any structure parallel to the bedding so that the coal is quite likely to break with a shelly conchoidal fracture in any direction, is one of the main physical characters of cannel coal. If we draw the line by this physical test, however, we shall include under cannel coal, a good deal of what is often called bone coal, which has very inferior fuel value, yet is really a low grade cannel coal. Practically the line is sometimes drawn arbitrarily at 20 per cent of ash, and any coal which has over 20 per cent of ash is not counted as a cannel.

To one who is unfamiliar with coals, the following tests may be of help. If the substance shows bright and dull bands and in burning, that which is left after it ceases to burn with a yellow flame, appears black and melted, and full of bubbles (at any rate under a lens) it may safely be set down as bituminous coal. If the heat is continued the glow lasts quite a while when removed from the fire, and it slowly burns away, losing most of its weight, to a white or red ash.

If the substance does not show well marked bands, frequently breaks with a smooth, shelly fracture, and if on heating, after it ceases to burn with a luminous flame the ash is white or red or soon becomes so, and retains the original shape of the fragment, and appears to be a considerable proportion,—over one-fifth of the original, it may be classed as black shale, if it splits readily parallel to the bedding, or as bone cannel coal if it does not. If on the other hand there is no fissility parallel to the bedding and the amount of white or red ash left after complete combustion is less than one-fifth of the original substances we may safely call it cannel coal.

Above the coal seams there are frequently a few inches which

*"On the border line of coal," Michigan Miner, Vol. II, No. 1, Dec. 1899, p. 17.

vary in character from bone cannel to black shale, and contain shells shaped like a tiny flat spoon of *Lingula mytiloides*.

Some of the material tested by Mr. Willcox (Chap. V, pp. 78-80) is of this bone cannel.

Beside the black shales associated with the coal there are others among Michigan rocks which have led to much waste of money. Most conspicuous are the Devonian black shales, which run across in a band from the south side of Thunder Bay to Charlevoix and Antrim counties, and from Port Huron and Detroit southwest. An analysis of one such shale, from south of Alpena, showing its fuel value is given in Part I of this volume on p. 47.

It will be noticed that the analyses of Michigan coals given in Chapter IV, most resemble among the analyses of other coals given for comparison, those of cannel and gas coals. This is especially true of the Verne coal seams. The very large amount of volatile matter which seems to be present makes an excellent gas coal, whenever a coal low in sulphur can be obtained. The Saginaw coal is very low in sulphur, and tests given below indicate that it would give a good fuel gas.

Comparing the three deleterious constituents, ash, sulphides, and volatile matter, and arranging the uses according as they can stand or prefer more or less of them, we get the following table:

Volatile matter	: Ash	: Sulphur
can stand much of the ingredient		
: gas man'f	: gas man'f	: steam making
: coking	: domestic	: domestic
: steam making	: coking	: coking
: smith work	: smith work	: smith work
: domestic	: steam making	: gas man'f

Presence of the ingredient disadvantageous.

Both the Sebewaing, the Wenona, the Jackson coal and in fact the Verne seams generally are coking coals, and when they are used as steam coal tend to run together, and mass on the grate unless properly handled with a special grate. In spite of the coking properties, the percentage of sulphur in the Verne coals is often too high to make good gas coal or coke without wasting. Water is also high. The sulphur combined with iron is more harmful in other ways than in heat production. Coals with iron usually give red ash. The Lykens anthracite coals are known as red ash coals and our Michigan coals are geological equivalents. A white ash coal is

probably pretty free from sulphur as well as iron. If in the analyses of the Sebewaing coal, we assume that there was originally enough iron which has all gone into the ash as Fe_2O_3 , to make FeS_2 of all the S, almost all of the ash must have been iron oxide and all the coal combustible except the water. The amount of heat given out by the Sebewaing coal is very considerable.*

Lignite or *brown coal* is a form intermediate between peat and coal, which is not found practically important in Michigan, though an important fuel in the far west (see analysis of Golden coal), and if present would not be likely to be used in the presence of abundance of coal. The same remark applies more or less to—

Peat, which is the consolidated mass of vegetable matter, largely moss, which is found in and beneath peat bogs, and is often called muck, but contains more mossy and woody substance than the proper muck, being composed largely of sphagnum mosses.

The cranberry marshes and tamarack swamps are the localities where peat most abounds, and up to the present peat has been known in Michigan chiefly as the base of the famous celery and peppermint soils, though for such culture, there must be about one-third of minerals constituents and sand; i. e., ash. In other words they are truly muck. Moreover they must not be acid. Peat frequently is. Analyses of these soils are given in Bull. 99 (July, 1893), of the Agricultural College. Peat has also been used, more especially the mosses which produce peat, as a packing for nursery stock.† Winchell‡ also has given quite an account of the various uses of peat.

Peat is the characteristic fuel of Ireland and has been used in other places for a long time, but its exploitation as a fuel has made great advances of late owing to the introduction of improved machinery in cutting and preparing it.§ It is also said to be available for the production of fuel gas, ammonia sulphate, acetate of lime, methyl alcohol, tar and coke briquettes,—that is to say, the same products which are given by the distillation of wood and soft coal.

There are a number of peat factories in Ontario, where there is no local supply of coal. It is said to sell for about \$3.75 per ton.

An unsuccessful attempt reported in Vol. I, Part I, p. 56, of these

*Chapter IV, Analysis A9.

†Sherzer, Monroe County, Vol. VII, Part I.

‡1860, pp. 192, 193.

§See "Die Torf Industrie" . . . " by Dr. Theodor Koller, published in Vienna. Hertleben, publisher, 1888.

reports was made to use it for fuel in pig iron manufacture. But beside the amount of water contained which runs from 10% up, it is liable to run rather high in phosphorus.

Peat bogs are very abundant in the northern part of the state* as well as in the southern and often occur in connection with, and sealing over marl deposits, and possibly they might be used in cement manufacture. Many descriptions will be found scattered through the reports of this survey from the time of Douglass Houghton on. Near Chelsea on the Michigan Central railroad are extensive deposits of peat, and the Chelsea Compresso Peat Co. has been organized to exploit them.†

The following analyses from Fritsche may be compared with Tables B and K of Chapter IV. Peat in the bog, it must be remembered, is very wet and entirely unfit for fuel, and the amount of drying and consequent loss of water in the merchantable product varies greatly. A peat with 16% water and 8.5 ash will yield about 3,800 to 3,900 calories. See p. 118.

	H ₂ O	C.	H.	O.	N.	Ash.
Harz, Germany.....	10-90%	50.86	5.80	42.57	0.77	0.57
Holland.....		59.27	5.41	35.32	1.79	2.04

ASH ANALYSIS.

	K ₂ O	NaO	CaO	MgO	Al ₂ O ₃	Fe ₂ O ₃	P ₂ O ₅	SO ₄	Cl	SiO ₂ Sol	Insoluble. (Sand.)
Harz.....	1.33	1.45	23.78	15.59	10.69	6.76	5.50	10.05	1.82	4.40	17.32
Holland.....	1.2	1.1	11.7	4.5	2.9	5.3	—	9.7	1.5	9.8	51.5

A few other terms often used by miners may also be defined.

Bone coal is a name applied to cannel high in ash, and to coal and slate inseparably mixed, and may show horizontal stratification. It represents a transition toward black shale, but need not be so compact, nor so uniform, nor necessarily so bituminous as cannel coal. A layer of bone coal overlies the main coal at Sebewaing, and is separated from it by a streak of sulphides.

Charcoal is a term improperly applied sometimes to slate and coal mixed, with stratification more or less twisted, and with FeS₂ more or less intermixed, as well as to the duller less altered streaks in the coal, which we have already described.

§ 3. Slate partings.

The mention of slate in coal naturally leads to the subject of "slate" (or more properly shale) "partings," which may be no wider

*E. g., 8 feet thick right in Redjacket; See Calumet News, July 31, 1901.

†Detroit Journal, August 24, 1901.

than a knife blade, but often are an inch or two thick, and though very thin may be persistent for a good way. They may even thicken so that what was mined as one bed of coal becomes several distinct beds. In the Glen Mary mine of East Tennessee, the superintendent informs me that the two seams of coal, separated only by a thin parting on one side of the basin, are three feet apart at the bottom, and on the other side have been followed continuously until they are at least forty feet apart. Similar phenomena occur in Michigan, especially in connection with the upper coals. This implies that the distance between different coal beds is not always the same, but may vary greatly. To such an extent is this true that Stevenson hazards the suggestion that possibly all the lower coal beds of Pennsylvania may be splits off from the one great Mammoth seam. This splitting of coal beds cannot be absolutely proved by comparison of disconnected records, but only by following them continuously in mines or in sections made by streams, but we have such proof in Michigan in the Wenona, and Michigan mines of Bay City and many of the records suggest the possibility of such occurrences.

§ 4. Character of the roof.

The usual beds above the coal are everywhere reported to be black shales, and in reports of explorations, unless great and conscientious care is taken, more or less of this black shale is likely to be counted with the coal. Sometimes this black shale is almost a cannel coal, and this is the case with the fossiliferous bed, the Lingula shale, which overlies the coal in the Bay City and Verne mines. Other varieties of the shale roof will be found described in Part I of this volume on clays and shales. The black shale is an impervious roof, which is important when water is so abundant as it is in Michigan, but is likely to be weak, especially when the rock surface is not far above, and requires a good deal of propping of one kind or another.

At times we find coal directly beneath clay, sand or gravel, or other unconsolidated deposits, when it is practically unworkable. Black shale with a firm sandy shale or sandstone above makes an excellent roof unless it peels off and comes down as "draw slate." A sandstone roof directly above will be found a very wet roof. I know of no mine that claims to be working under a limestone roof, though the roof at the Michigan and Amelith shaft of the Pittsburgh is a black bituminous limestone full of shells (*Productus*, etc., see

p. 42), which are like those found at Verne, and the roof of Tod Kincaid's coal mine near Corunna is said to yield 50 per cent of CaCO_3 . Probably limestone beds are pretty widely associated with the Verne coals.

It is probable that our coals belong in the Pottsville formation, corresponding to the Sharon, Quakertown, and Mercer coals of Ohio, and the limestone roofs are especially found over the Upper Mercer coal and the coals of the Lower Coal Measures. The weakness of the roof has been the ruin of many mines. Next to the water it is the most serious source of expense.*

The deeper coal seams nearer the center of the basin may be expected to be better as to roof.

As we have said, in Michigan the shale above the coal is almost invariably black. Sometimes blue shales are reported, and it is generally blue a few feet above. In fact so characteristically do our Michigan coals appear to be associated with shales, and so rare are the cases when anything but shale, slate or fire-clay, are reported above or below, that they may be presumed to be generally mere local phenomena.† In the overlying shales are very often nodules and bands of carbonates of iron, lime, etc., kidney ores as they are often called from their shape. A very interesting occurrence is that of the nodules which also contain sulphide of zinc with sulphide of iron, which I found in the shales over the coal in the Owosso Coal Co. mines northeast of Corunna; also at Grand Ledge, at the Standard mine Saginaw, at Sebewaing and at Flushing, and also I am told in the shaft on Sec. 7, of James Township, T. 11 N., R. 4 E. I have also found kaolinite.

As we shall later see, there are a number of reasons for considering one of the coal seams mainly worked in Michigan, as nearly equivalent to the Sharon or Massillon coal of Ohio, and it is interesting to note that White‡ speaks of the roof of the Sharon coal as commonly 40 to 50 feet of shale with nuggets of Fe CO_3 .

§ 5. Character of the foot.

The bed underneath the coal (the foot) is usually reported as fire-clay or shale. Probably no stress can be laid on the difference, except that by fire-clay a white or light color is generally implied. Many drillers report all clayey beds under coal as fire-clay, where other drillers report always shale, and a record of a saline or other well for water might report the whole series as merely alternations

*Lawton, 1887, p. 133; 1886, p. 173, et passim.

†The difference between what the drillers call "slate" and shale appears to be that the former is harder and slakes less readily.

‡Bull. U. S. G. S., No. 65, 1890, p. 202.

of black, white and blue shale. Fire-clays are shales which will not melt in the fire and will make good fire-brick. They have a large proportion of fine SiO_2 (which is not surprising when we remember how largely plants like scour rushes occur in the coal), and have but little of fusing compounds, like alkalies, lime, etc. As Ries's tests in Part I of this volume show, genuine fire-clay is absent or rare, but clays suitable for making semi-vitrified or paving brick are common. For low grade fire-brick and paving brick, the demand for which is growing, such clays may often be mined to advantage in connection with thin seams of coal.

§ 6. The Michigan coal basin.

The outlines of the coal basin have been shown in Winchell's various maps of Michigan, in Volumes III and V of these reports,

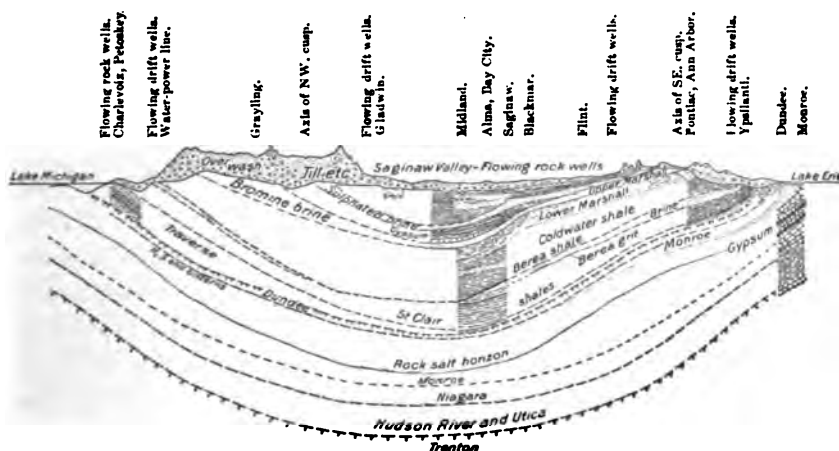


Fig. 1.—Cross section of the Lower Michigan Basin. Horizontal scale, 1 mile = .135 inch; vertical scale, 1,200 feet = .321 inch.

and in Nos. 30 and 31 of the U. S. Geological Survey water supply and irrigation paper. A rough map was also given in the preliminary addition of these papers, and in an article in the Engineering and Mining Journal for June 30, 1900, with contours also indicating in a rough way the system of rock channels.

Plate I of this report illustrates our present knowledge. In the Marshall sandstones themselves small streaks and pockets of coal and coaly impressions of vegetation are found also, but have never been found to possess more commercial importance than the drift-wood along the beach.

Figure 1 and description taken from my paper on the water
4—Pt. II

supply of Michigan* gives an idea of a cross-section of the strata of the basin from southeast to northwest, only those of the innermost basin above the sulphated brines being the coal measures.

The Devonian black shales are those which lead most often to false reports of coal.

The area enclosed on the map, Plate I, includes also the basal or Parma sandstone, which is, however, not everywhere present. The boundaries of the basin are fairly well known east of the Meridian line, but the northwestern portion is more uncertain. All that we have to go by are certain general considerations as to the thickness and dip of other beds, the relations of the drift and the present topography to the underlying topography, the coal in the drift and the direction in which it came, etc., which are almost too complex to go into here,† and a few scattered drill holes.

Some distance beneath the coal series proper there is a sandstone known as the Napoleon or Upper Marshall, which can be followed in outcrops or in drilled wells from the sandstone bluffs of Huron county into Sanilac and thence southwest past Island Lake and Napoleon into Hillsdale county, and thence northwest, past Battle Creek to Holland, and thence, in wells, on to Grand Haven, Muskegon and Ludington. It is also recognizable in wells around Tawas and northwest, and since it is full of water, which over much of the Saginaw valley will rise to the surface, it has been tapped by a great many wells, for fresh water near the margin, for salt and bromine toward the center. We can thus follow it pretty continuously over two-thirds of the basin.

The greatest depth below surface to which it has been followed is at Midland (1200-1300 feet) and St. Louis and Big Rapids (1300 feet). The outcrop, or what would be the outcrop, were the surface deposits stripped off, is generally under higher land than the surface of the coal basin, which it thus surrounds as a rim. This bed is practically equivalent to the Upper Logan of Ohio. *Beneath it and outside it no coal in commercial quantity has been or is likely to be found.*

This point needs to be emphasized, for in the Detroit papers of

*Water Supply and Irrigation paper of the U. S. Geological Survey, No. 30, Fig. 10.
†The cusp dividing the Saginaw and Erie ice lobes we know followed on the southeast the ridge of Marshall sandstone underlying the coal basin. So on the northwest it is a fair presumption that the dividing cusp between the Saginaw ice lobe and that of Lake Michigan, which retired north and northwest from Grand Rapids, followed the heavy sandstones underlying the coal basin,—either the Marshall or the Parma.

Again coal in the till or terminal moraine deposits must have been derived from a source nearer the center of the ice sheet along the direction of lines of motion of the ice. Coal in alluvial deposits must have come down hill.

The coal series appears to have been well represented in the Big Rapids Red Cross well, and coal is found in the drift as far north as Roscommon county. Now coal in the till has always been moved to southwest of the rock outcrop.

March, 1898, I saw a write-up of two columns concerning coal in Wayne county, and not many years ago considerable time and money was wasted in putting down a shaft for coal in Antrim county. More recently some of the pushing business men of Alpena underwent the same experience, and even now, I hear of coal explorations in Sanilac county, at New Baltimore, etc., which are sure to be futile. To explorations for coal outside the limits shown upon the map I can give no encouragement.

It was at one time supposed that the coal fields of Michigan, Ohio and adjacent states were originally continuous and were afterward folded very gently, and the coal on the arches eroded away, while that in the basins being less exposed to such action was preserved. Such was often the case in Pennsylvania. But it is now understood that these fields were never continuous.*

This is of practical importance, for if they had been we might expect to find occasionally outliers outside the main basin. The evidence in the case of Michigan is somewhat as follows: We find overlying the Marshall sandstone, in the deep wells of the Saginaw Valley, a series of shales with beds of gypsum which extend from Alabaster and Huron county to Grand Rapids, where they outcrop.

Now the gypsum (sulphate of lime) is a salt present in seawater, and one of the first to crystallize out, when an arm of the ocean is cut off from the main body and exposed to a climate such that evaporation goes on faster than water is supplied. This gypsum we do not find in Ohio, or other states. Hence it is natural to suppose that the gypsum was laid down in an enclosed basin cut off from the main ocean to the south. As a matter of fact we do find a group of strata, the Logan series,† which occur in Southern Ohio, but not in Northern Ohio where an unconformity indicating that that part of the State was then out of water takes their place. In the same way we find that in Michigan the gypsum series does not extend all over the top of the Napoleon sandstone where we might expect it, but that in some places the beds immediately above—the limestones of Grand Rapids and Bayport—lie directly on top of the Napoleon sandstone. Or as at Corunna, we find the Parma and Marshall sandstones indistinguishable. Again over in Ohio, we find a limestone which must from its fossils be equivalent to these limestones, the Maxville limestone, unconformably overlapping the beds below. Thus we have evidence of a neck of land

*Keyes, Iowa, 1894, p. 173.
†Orton, Ohio, 1888, p. 39.

projecting out from the land mass to the north (for Canada seems to have been out of water all this time), through Southeastern Michigan and Northern Ohio, having no deposits of Logan age, and hence a projection of land. We thus have a slight fold indicated, antedating* the formation of the coal measures of Ohio and Michigan and lying between them. The only way in which we can conceive the two coal basins to be connected therefore, is by submergence of this axis, and deposition over it. It is not of course necessary to suppose that the submergence extended to the full height of the fold, which was very likely folded as formed. Of complete submergence of this axis there is no sufficient evidence though this low projecting area seems to have been a little higher in the time of the Upper Marshall, i. e., Napoleon, than immediately thereafter. During the time of the Bayport limestone it sank a little, but the character of that limestone and the corals and sand bars and other shallow-water fossils found in it indicates that the depression was not enough to make the ridge entirely disappear.

Almost immediately above this limestone come the coal beds. Over in Ohio fragments of the Maxville are found in the conglomerates immediately above† (Herrick) showing that the movement of depression during which the limestone was formed must have been promptly changed into one of uplift which brought it within reach of erosion, so that its fragments could be worn away to be laid down in later formations. So around Jackson this limestone occurs on the tops of hills with the coal beds and coal measure series between and flanking them‡ in a way that plainly indicates that the coal measures were deposited in troughs in the eroded limestone, so that the margin of the basin at the time of the deposit of these coal measures must have been in the region. It must not be supposed that the smooth outline of the coal basin given in Plate I is exact. It is merely the expression of our ignorance of details. It was probably very irregular and would have been more deeply indented if it had been taken at the top instead of the bottom of the Parma sandstone.

Inasmuch as coal cannot be predicted as certainly present any-

*A reason for considering that the fold of the Marshall antedates the coal seams is found in the dips. While the top of the Marshall descends from 252 to 700 or 800 feet below the surface from Sebewaing to Bay City and Saginaw, the base of the coal measures descends from 104 or 120 to between 300 and 400 feet only; while it is doubtful if the coal seams descend appreciably.

†Geol. Sur. Mich., Vol. VII, Part II (Huron County), p. 293.

‡Geol. Sur. Mich., Vol. III, Pt. I, pp. 116 and 129, and private communications of J. Holcroft and F. C. Ward of Jackson; see also Winchell, 1860, p. 117.

where in the coal basin, I have in drawing the limits of it tried to include all the land where it might even *possibly* be present.

As to the limited character of the coal basins in other states of the Mississippi Valley, says Orton of Ohio.* "The subsequent," to the time of the Berea grit, "history of the eastern half of the State depends upon the joint advance of these land masses, the western and northern borders of the gulf. Both seem to have extended themselves in the same manner by a slow and nearly uniform rise of the border," "the lowest coal seam was formed around the margin of the sea;" "the later coals never extended over the outside margins of the earlier swamps." "At the time when the Sharon coal was forming, the area of the gulf in Ohio was not less than 10,000 square miles."

Says Keyes:† "It is a significant fact that the Palæozoic coals of the world are all deposited in more or less limited basin shaped areas."

Winslow‡ gives a map of Missouri, which shows quite well one-half of the basin as it exists there and§ describes the Coal Measures as flanking the Ozark uplift, which took place probably during the Carboniferous.

The following diagram, which is taken from Part II of Vol. VII modified from one issued by Keyes|| (Fig. 2), shows the general sequence of elevation and depression of the land and consequent advance of the shore to the south or retreat back to the north.

The land rose and the ocean retired south during the Kinderhook (Marshall), and Lower Michigan in part emerged from the water, and continued retiring more slowly during the Augusta while the gypsum series was being deposited in Michigan in the cut off basins. The ocean advanced again during the time of the Saint Louis formation and finally at the time of the Bayport limestone forced open water communication as far as Huron county. Then it retired again during the Kaskaskia so that the Bayport limestone was eroded around the edge,—at Jackson and elsewhere.

The upper Kaskaskia (Chester) and the very lowest coal measures were deposited only in the center of the coal basin, if indeed, that too was not land surface. Then during the time of the coal measures though there was some irregular readvance of the sea it

*Ohio, 1884, p. 135; 1893, p. 264.

†Iowa, 1894, p. 91.

‡Mo., 1891, Plate 1.

§Mo., 1892, pp. 109-110.

||Iowa, Keyes, 1894, p. 114.

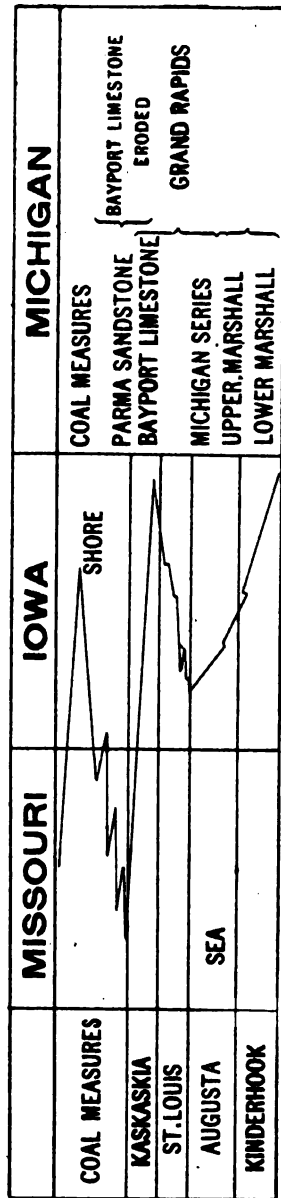


Fig. 2.—After Keyes (Iowa, Vol. II, p. 114) showing how the shore line advances to south and returned north during and before the deposition of the coal measures.

never fairly regained what it had lost, for it filled up nearly as fast as the land sank.

There is another point that shows that the Coal Measures of Michigan were deposited in an arm of the sea, extending into a basin which existed before their formation, and that they have not been folded into basin shape since. Beneath Sebewaing the Upper Marshall, Napoleon, is struck at about 250 feet* and the coal bed is from 85 to 125 feet in depth. At Midland the top of the Napoleon is at 1,200 feet depth, and consequently the coal horizon might be expected at some such depth as 1,050 feet if the strata were parallel. Instead of this at 1,050 feet we are in the gypsum beds of the underlying Michigan series, and we do not find any possible equivalent to the Sebewaing coal until we come to a black shale at 800 feet. The same state of affairs is generally true in the Alma, the Saginaw River wells,† etc. While the Napoleon is often over a thousand feet deep, proper coal measures are not found at over 800 feet depth.

Obviously, therefore, the coal formation is in a broad way more nearly horizontal than the Marshall sandstones and underlying

beds, which must have been slightly folded before the coal was laid down. It follows that we cannot estimate the thickness of the

*Vol. VII, Part II, p. 145.

†Chapter VII.

coal series from their breadth and the dip of the Marshall. However, the earlier estimates, and in fact the estimates to this day current, concerning the thickness of our Michigan coal measures, being based mainly upon observations near the border, have much underrated them. Keyes for instance speaks of them as not over 200 feet thick, half of which "is occupied by the basal sandstone." Instead of this there is not less than 600 feet of coal measures, excluding the basal Parma sandstone, at Midland, and probably somewhat more farther northwest.

§ 7. Minor undulations in the coal measures.

The coal lies in minor undulations, independent of the general curve of the whole formation and the basin which it forms. These are known to miners as "hills" or "rises," and "valleys" or "swamps." The coal is said to be pockety.

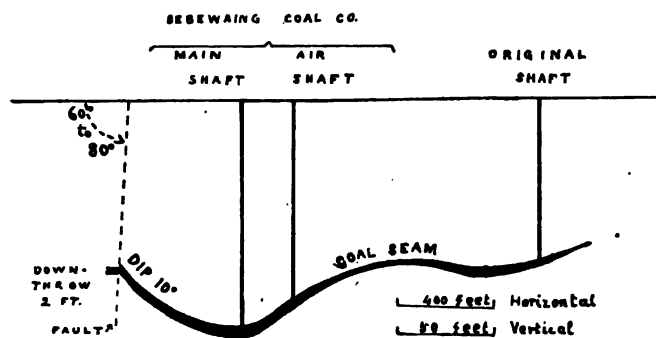


Fig. 3.—Section at Sebewaing Shaft.

Fig. 3, taken from Fig. 11 of Part II of Vol. VII, across the Sebewaing basin shows the structure. It appears again in the diagram of the Woodville shaft, Fig. 4.

I have been informed by the miners at Corunna that the rule is generally true there, and that as Rominger says, "The beds are found in the mine rising and sinking in undulations." At the Somers No. 1 shaft, St. Charles, again the coal is reported to be dipping and thickest to southward. Between Somers No. 2 shaft, and the St. Charles Coal Co.'s shaft are two rises. This is a very important feature in developing coal, for it is obvious that it will be much more economical and convenient to locate the shaft at the lowest points. Then in drifting out, all the water will run toward the shaft, the levels will be kept dry and the water can be lifted by

one pump. Moreover the loaded cars will have a down grade, and the empty cars an up grade. A similar structure is described in all other States. Keyes* describes and shows in his figures very plainly the "shallow saucer shaped sheets of coal." Orton† mentions the same structure in the Sharon coal.

These minor undulations seem also to extend down into the Napoleon as we find in following the "lower salt rock" from brine well to brine well down the Saginaw River.

In the Pere Marquette No. 1 mine the coal rose so rapidly to the east that the roof became unsafe and leaky, and the mine is being abandoned and similar undulations might be described from most of the new mines.

In the works of the New Hope Coal Mining Co. near Jackson the trough or valley is barely 150 yards wide, but is several hundred feet long.

In these undulations the coal is generally thicker where lower, and "thins to the rise."

This is the general rule laid down in the text-books.

This is obvious in the workings of the Sebewaing Coal Company, Fig. 3, where the coal is $4\frac{1}{2}$ to 5 feet thick near the shaft, and diminishes to two or three feet at the old first shaft, and beyond that runs out. At the former shaft it is 120 feet deep, and at the latter 86. It is true according to Mr. Holcroft generally in the Jackson region (Fig. 4, p. 33 and Fig. 5, p. 48), and also is known to be true around Corunna.

We find the same law reported for Iowa by Bain‡ and Keyes.§

"The coal may therefore be considered"—"as disposed in numerous basins of more or less area, thickened centrally, but gradually becoming attenuated toward the margins."

Similar facts are mentioned in Ohio by Orton.||

In the lower and thicker parts these troughs of coal are likely to be capped by a smaller coal seam known as a rider.

As the word likely implies, this rule has not been made out with any certainty in Michigan, though we find in the East Saginaw coal mine for instance, above the 3 feet 3 inches of coal at 147 feet a 4-inch rider at 128 feet 7 inches, and another of 1 inch at 104 feet.

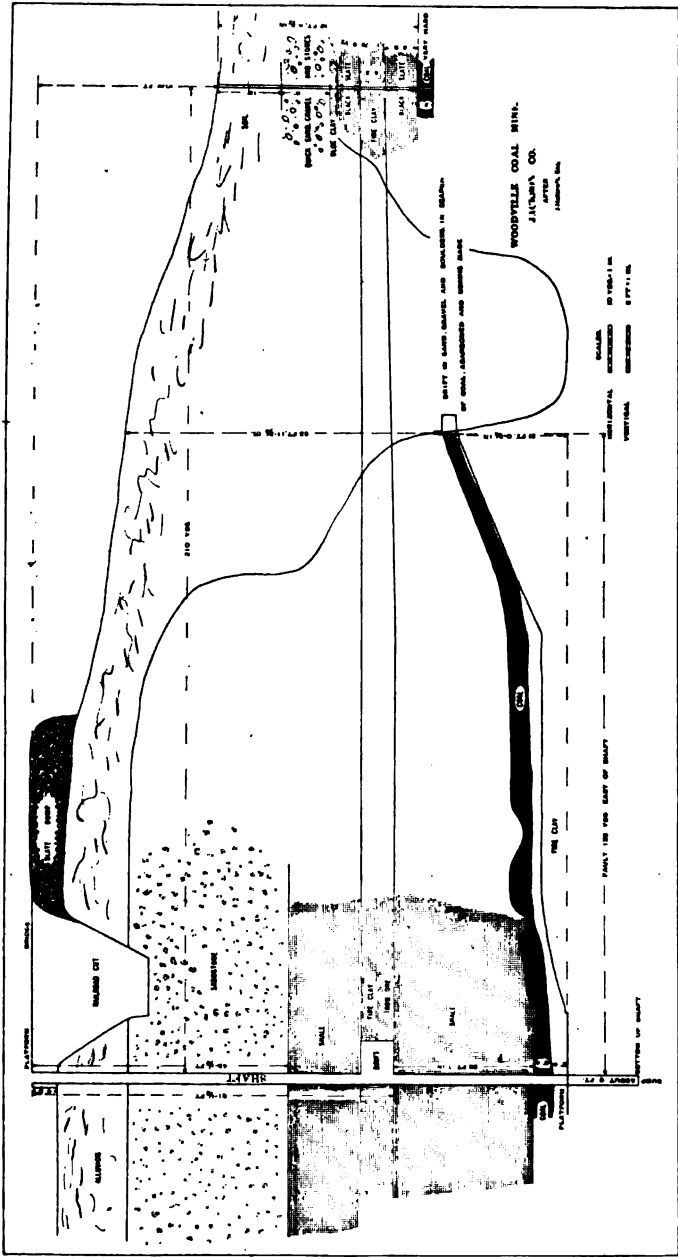
*Iowa, 1894, pp. 176-179.

†Ohio, 1884, p. 156.

‡Iowa, 1897, p. 299.

§Iowa, 1894, p. 176.

||Ohio, 1884, p. 156.



5-PT. II

Fig. 4. Section at Woodville Shaft. Illustrating the occurrence of a gravel filled channel or washout, and of undulations and pinches in the coal.

So, too, around Sebewaing, when the main coal is from 85 to 105 feet deep, we sometimes find a little rider at about 71 feet. In naming and correlating the seams I have found it convenient to entitle them thus, in descending order: Upper rider, Upper Verne, Lower Verne, Middle rider, Saginaw, Lower rider, Lower coal. I would not pretend however, that seams which I have thus named are always the same. I know well that my correlations are far from perfect. Nor would I imply that the seams called riders may not at times be thick enough to work. The East Saginaw mines may be on the Middle rider.

This law has been especially developed by Bain,* who gives a theoretical explanation of it, that the shrinkage and contraction of the lower coal bed, which if five feet thick represents about 60 feet originally of peaty matter, in slowly settling and compacting, made a basin in which the upper coal was formed. If his explanation is correct the phenomenon should be widespread, and the presence of riders is also alluded to by Nicoll† as a favorable sign. Thus we may safely say that the presence of small seams of coal is not unfavorable to more coal below.

§ 8. Variation in coal measures.

No one bed of coal extended over all the coal basin.

This is obvious if we regard the coal basin as it now is, for many of the records like those of Alma, St. Louis, St. Johns and Ithaca, which are close to the center of the basin, show no coal. But this might be laid to the subsequent cutting out of the coal, just as the original East Saginaw well‡ struck a big sandstone which replaced all the coal measures down to 171 feet, including the bed at 147 feet which is now worked. But we find a number of the records in the center of the basin lacking coal, and though it is proverbially hard to prove a negative, on close comparison of the records it is hard to see how any one bed could have been represented all over the basin. We find the coal beds at all sorts of altitudes above the Napoleon from 163 feet at Sebewaing to 1,005 feet at Midland. The deep central wells show black shales and bituminous limestones at horizons where coal appears at the sides. As Rominger says on this point,§ "Regularity in the sequence of strata does not exist in the coal formation. The beds in it are usually of local extent,

*Iowa, 1897, pp. 290-300; *Journal of Geology* III, p. 648.

†*Story of American Coals*, Phila., 1897.

‡*Geol. Sur. Mich.*, Vol. V, Part II, p. 55.

§*Geol. Sur. Mich.*, Vol. III, 1876, Pt. I, p. 128.

so that a position which in one place is occupied by a shale bed may in a neighboring locality be filled by a ledge of sand rock." "The whole series is a constant alternation of shale and sandstone beds, every natural or artificial section teaches us that an immense variety exists in this alternation." Says Keyes,* "Few cases are at present known in which the geographical extent of a workable coal stratum is more than four or five miles."

Also Bain,† "Barren holes are frequently put down in the midst of productive fields, particularly in the Iowa-Missouri region."

We see therefore that we must not be discouraged by the failure of one hole in coal explorations, and on the other hand it requires much more testing to be sure how much coal we really have than it would if the coal were more regular. Bain's detailed sections‡ and our own on Plate IX show well how irregularly the coal is distributed.

In the same way, Orton, speaking of the Ohio coals, says that to expect the earlier formed seams in the center of the basin would be to look for the living among the dead,§ that in no case known does the coal extend beyond 600 to 800 feet below sea level, and "there is no instance known in which the Sharon" (one of the lowest coals) "has been found of mineable thickness directly under a mineable thickness of the Kittanning coals." "A coal seam can often be traced toward the interior of the field along some open valley, or by means of a series of test borings. In numerous instances such seams are found to suffer gradual reduction." Again (p. 135), "The later coals never extended over the outside margins of the earlier swamps. Of Missouri Winslow says,|| 'No one coal bed in Missouri can be affirmed to be co-extensive with the area of the coal measures, and within a still smaller area does any one bed possess those characteristics of thickness and quality, or is it accompanied by the other conditions which go to make it workable.' The 'conditions' which he cites as preventing its workability are inadequate thickness, poor roof, disturbances which have produced faults—and faulty coal, inferior quality, excessive water, excessive depth.

Of these conditions the last, excessive depth, is not likely to occur in Michigan, except that where the coal is deepest the cost of drill-

*Iowa, 1894, p. 176.

†Iowa, 1897, p. 232.

‡Loc. cit., Plate VIII.

§Orton, Ohio, 1894, p. 262.

||Winslow, Mo., p. 33; see also pp. 24-25.

ing it up to see how much there is becomes excessively great. But once found in satisfactory quantity and quality the depth will never be a serious obstacle.

Examples of the running out of coal seams in our Michigan properties might be multiplied and it would be invidious to select examples. In one direction they very often pass into black shale, the transition being marked by bone coal or cannel coal.

The coal is more abundant, not far from the margin of the large general coal basin. The coal beds diverge and thin out gradually as they get deeper and lower coals come in. The remaining series thickens toward the center of the basin; in other directions they thin irregularly and suddenly.

Jackson and Sebewaing are on the extreme verge of the coal basin. At Williamston, Saginaw and Corunna, the basal sandstones are not much over 400 feet deep anyway.

Monitor is nearer the center. Wells still nearer the center at Lansing, St. Johns, Midland and Alma, have not shown much coal.

The irregular thickening and thinning in other directions has been touched upon under other heads, and will be referred to again when we come to treat of sandstone channels and bars. It may be noticed in reviewing the records of various explorations that the sudden disappearances of the coal have not been generally in the direction of the deeper part of the basin. In regard to other States in addition to what has been already quoted, Orton remarks:* "All of the coal seams below the Freeport horizon and a number above appear to have been formed as marginal swamps around the border of the sea," and the description of the Jackson county (Ohio) coal mines† that work in the Wellston coal which is "not more than 2½ miles wide and 7 or 8 long;" "on the northern edge of the basin;" rising "growing thinner" "down to a feather edge," "on the southern side" "running into shale and never met farther beyond," shows the mode of occurrence clearly. Winslow‡ gives a figure and frames his hypothesis to explain, "b. How coal beds are more abundant over the marginal area." What White says of the lower coals is quoted below.

As to the question of the parallelism or divergence of coal seams, geologists have held very different opinions. Andrews, in Ohio,

*Ohio, 1884, p. 135.

†In *Mines and Minerals*, Jan., 1899, p. 254.

‡Mo., 1891, pp. 30-31; see also previous pages and p 52.

insisted upon the parallelism of coal beds (coal horizons) and Lesquereux held the same views, and both were experienced workers.

On the other hand, Stevenson and others have brought indisputable proof that coal beds have sometimes diverged from one main mass, and indeed Stevenson has suggested that a whole family of coal seams are but splits from one main seam. Keyes* has made a very plausible attempt at reconciliation in his supposition that the geologists who found a parallelism followed the coal along sections more or less parallel to the shore line of the great arm of the sea in which they were formed, while those who found a divergence studied sections running away from the margin of the basin. Certainly this applies to Stevenson's observations.

Let us see how Keyes' hypothesis will apply in Lower Michigan. The only part of the basin from which we have anywhere nearly enough data to test the matter is the southeast part between Sebewaing and Jackson.

In this direction the general trend of the coast in Carboniferous times was from southwest to northeast. Let us then first compare series of drillings and sections running in about that direction, in which the top of the Marshall sandstone is between 600 and 700 feet deep.

In the Bay City wells the Marshall is deeper,—in the very deep one at the works of the North American Chemical Co., the Napoleon Upper Marshall extends from 850 to 970 feet in depth. Gypsum is conspicuous about 130 to 200 feet higher, and the Parma or upper salt rock seems to be 360, extending between 490 and 540 feet. Immediately above is a thin stratum of coal near 480 feet. Now we have at Munger, through the kindness of Capt. Blodgett, a record which shows 60 odd feet of sandstone below 348 feet and a coal similarly just above it. This sandstone we may safely take to be the Parma, and we may infer that the top of the Napoleon would be about 700 feet deep. In the upper 350 feet we have not less than four coal horizons sometimes cut out by sandstones, the intervals being 16-90-52 feet. Between 140 and 160 feet are two quite persistent coals about ten feet apart.

Passing now to the old first well of Saginaw put down by the East Saginaw Co., and recorded by H. C. Potter, we find the

*Iowa, 1894, pp. 164-171.

Napoleon sandstone at 637 feet, the first strong brines at about 487 feet (gypsum?) the Parma sandstone apparently from 293 feet 9 inches to 399 feet 1 inch, and no coal mentioned immediately above, but from 246 to 256 feet and from 229 to 233 feet were signs of coal. The upper part of the series is replaced by 78½ feet of brown sandstone. While this does not at first appear to match at all we find not far off at Crow Island a black soapstone resembling coal just above the Parma, and 44 feet above it a coal seam. Thus the lower seam is locally absent, and the second seam is the first met in the East Saginaw hole. A boring on C. K. Eddy & Sons' land 700 feet south of Genesee avenue, however, about a mile and one-half farther southwest, near which the Napoleon is struck at about the same depth as around the last well gives coal at 282 feet 3 inches and 203 feet 5 inches, and black slate at 196 feet, etc. The rest is cut out by sandrock. At South Saginaw where an old record with samples shows that the Napoleon is struck at 715 feet, and the Parma 375 feet above at 340 feet, bituminous black shales, occur from 305 to 318 feet—22 feet above, which may replace the lower rider and coal, while higher up at 180 to 200 feet is a coal reported in a great many records, apparently that mined at the Pere Marquette No. 2, the Chappell-Fordney, and the Riverside shafts. In the next seventy feet above are three coal horizons, the intervals in one case being 5-17-31 feet. So, down southeast across the Prairie Farm toward St. Charles, we find the Saginaw seam continues in spots, at somewhere about 190 feet, while above it are at least three coal horizons.

At Garfield there is an old salt well, now flowing. Though the lower salt rock is said to be 800 to 860 feet deep the upper salt rock with a very strong water is from 400 to 450 feet; while between them is said to be much lime rock. A recent well near by found two coals at 130 and 139 5÷6 feet which may be the Verne coals, and a mile and a half east the Saginaw coal comes in at 192 feet. At St. Charles a little farther on the Napoleon is about 700 to 810 feet deep. Below 500 feet is much hard lime rock. Above it is probably the Parma. At 425 feet it is said that there is coal, the lower coal horizon, while the main coal mined in five shafts around St. Charles is the Saginaw coal, from 180 to 220 feet deep. At 128 to 143 feet or thereabouts is quite a persistent vein of sulphury coal about two feet thick, and there are a couple of horizons still higher. (See Plate IX.)

Going into the Owosso district, we find to the northwest of it, comparing Rominger's and Winchell's account of the borings near the Detroit and Milwaukee station* and near Six Mile Creek, that there are from two (at 17 and 36 feet) to four coal beds near the surface, with one or two far down at 147 to 180 feet. Going still farther southwest to Grand Ledge, and putting together Rominger's descriptions of the outcrops and the artesian well of the Mineral Spring Hotel with Winchell's description of the explorations near Millett on Sec. 35, Delta T. 4 N., R. 3 W.,† we find from two to four coal horizons exposed by the river, and another coal seam some 73 feet below.

It is obvious that these sections do have a general resemblance and parallelism, though they differ in many minor details, which may to a certain extent be merely due to imperfect records. They all lie also in a general northeast-southwest line, roughly parallel to the margin of the basin.

If now we take a series of records lying in a line at right angles to this line, we shall find much more marked difference, so that it is extremely difficult to see the equivalent strata. Take, for instance, the fairly close series of records made by Durand‡ and the 907 foot and other borings around Corunna,§ the borings at the D. and M. Station at Owosso and four miles northwest by Mr. Courier on Sec. 57, T. 7 N., R. 2 E., also those of the St. Johns water-works well, and the wells at Ashley, Ithaca, and Alma and St. Louis. We find marked differences and divergences, extending down into the beds below the Coal Measures proper.

In the Durand well, it is probable that the water bearing strata from 174 to 238 feet under the brown shales represent some part of the great series of sandy strata beneath Corunna (on Sec. 22) from 231 to 471 feet.** This series seems to correspond to the whole series of sandy strata from 250 feet down to 601 feet in the well at Owosso (Sec. 5, Pl. XLV of Vol. V), which is, however, split by a series of limestones and shales that I take to be the Michigan series. These limestones and shales may in the Corunna well be represented by marginal sandy strata, or not be represented at all according as

*Winchell, 1861, p. 125; also Vols. III and V of these reports.

†Winchell, 1861, p. 124; Vol. III of these reports, p. 133.

‡For farther details see the last chapter of this report.

§Geol. Sur. Mich., Vol. V; see also Rominger's and Winchell's Reports cited, and Lawton's Reports as Commissioner of Mineral Statistics.

**The reference in the record to hardpan and stones is probably to a conglomerate, for bedrock is usually struck at from 75 to 175 feet deep, and the water is higher in salt and lower in lime than shallower wells which are certainly in the drift.

the land margin was between Corunna and Durand or between Corunna and Owosso. In any case we have the Corunna sandstone series split once. Then passing from Owosso to St. Johns we find from 264 feet to 435 feet a series mainly of sandstones which must in some degree correspond with those from 250 to 473 at Owosso. Only 28 feet above we come to another sandrock which Winchell might call the Woodville. But the 26 feet of shale can hardly represent all the coal measure series. The shale may be another wedge splitting the great mass of shore sandstone. Then we pass on to Ithaca, which is quite a jump, partly bridged by wells near Ashley (which show down to 217½ feet mainly red sandstone, with coal and light and dark shale in the last few feet), and here we find a little red sandstone and shale near the top, but mainly a series of shales with five beds of dark limestone or black shale which might be taken as equivalent to coal horizons. Underneath this we have 86 feet of light-colored sandstone and then shale again. If we allow for a dip of not more than 15 feet to the mile, and we cannot well allow more, this Ithaca sandstone would correspond to that at St. Johns from 264 feet down, but is much less thick. In that case the St. Johns shale series has swelled and diversified enormously at the expense of the sandstone, and the Ashley well coal stands between the upper and lower sandstones at Ithaca. Then only six miles or so farther on we have at Alma and St. Louis some deeper wells which enable us to see quite definitely where we are. The Napoleon has shrunk from what it was in Owosso—from 65 to 47 feet. The Michigan series above it is characterized by gypsum beds as well as limestone, and is 225 feet thick instead of about 63 as at Owosso. Then we have the Parma sandstone well marked from 710 to 790 feet thick. Now, at 615 feet and 710 feet, are signs of coal horizons. There are two sandstones above it, separated from each other by blue and black shales. Is the lowest only of these three sandstones continuous with the great mass of sandstone to the southeast around Owosso? Probably not, for a dip of fifteen feet to the mile which is probably more than there really is, would make the sandstone at 637 to 675 run into that at 525 to 611 at Ithaca, and the same dip continued would make it split from the great sandstone at Owosso. But the uppermost sandstone, in the Alma well from 500 to 550 feet, and 300 feet down in the shallower St. Louis wells, may be the upper red sandstone of St. Johns and Ashley, and not appear at all around Owosso.

If leaving Alma we pass toward the northeast, i. e., parallel to shore, we find at Midland a record which can be very closely paralleled with that at Alma.*

Turning to the coals; the couple of coals, often workably thick near Corunna, are represented by more numerous coals, and some deeper coals near Owosso, which incline to be thinner. Near the center of the basin we have limestone in their place, and the coal indications appear above another large sandstone, which may correspond to Winchell's Woodville, or may be a split from the Parma, while black shales may represent some of the other coal horizons.

Thus we see indications of the kind of divergence that Keyes' hypothesis would lead us to expect.

The formations above the Napoleon are thicker in the center of the basin. But this is not simply by addition to the top of the series, but full as much by addition and expansions to the bottom of the series. The coal mined around the margin of the basin resembles in chemical character, that is per cent of sulphur and volatile hydrocarbon the higher coals of the center of the basin.

§ 9. Low position of the Michigan coal seams.

Though the limestone underlying the coal series is equivalent to the Maxville in Ohio and the top of the St. Louis limestone of the Mississippi River, the age of the coal beds cannot be directly inferred inasmuch as there is generally an unconformity between it and the beds containing the coal seams. It is possible that near the center of the basin at such points as Midland, Alma and St. Louis the sedimentation may have been continuous, the Kaskaskia limestone being present as well as the St. Louis and the deposition of sediment being uninterrupted until the time of the coal deposits. This was not so at the margins. All the indications are, however, that all our series are low down in the coal measures (Mesocarboniferous), in fact in that section of it known as the Pottsville formation, "Serial conglomerate" or "millstone grit," a part of the series which was once supposed to be below any important coal seams, though it is now known that some of the best coals of the United States, the Lykens valley of Pennsylvania, the Pocahontas and New River of West Virginia, the Sharon, Massillon and Mercer coals of Ohio, belong to this series.

*Water resources of the Lower Peninsula of Michigan, U. S. Geol. Survey, 1899, Water Supply paper No. 30. Fig. 11.

The evidence that our coals belong in this the lowest of the formations producing coal in commercial quantities is as follows: The fossil shells have been submitted to Dr. C. H. Girty of the U. S. Geological Survey who writes as follows:

"I have identified the following species:

Central Mining Co., Bay County.

Lingula mytiloides Sow.*

Wenona Mine, Bay County.

Lingula cf. Tighti Her.*

Verne Mine, Saginaw County.

Orbiculoidea sp.

Chonetes flemingi Nor. & Prat.*

Productus prattenanus Nor.*

Productus (Marginifera) muricatus Nor. & Prat.*

Orthoceras rushense McChes.

Soleniscus sp.

Michigan Mine, Bay County.

Lingula mytiloides Sow.*

Chonetes Flemingi Nor & Prat.*

Productus prattenanus Nor.*

Productus (Marginifera) muricatus Nor. & Prat.*

Avicula acosta Cox.*

Pleurophorus oblongus Meek.*

Nucula ventricosa Hall?

Trepostira sphaerulata Cow.*

Orthoceras rushense McChes.*

Large nautiloid.

Fish bone.

"The form which I identify as *L. mytiloides* has been so identified by Meek and many other America paleontologists. I am not sure that it is the same as Sowerby's species. The same is true of *Orthoceras Rushense*, the Michigan shells belonging to the form popularly referred, I fear incorrectly, to McChesney species. *Lingula cf. Tighti* may possibly be only young specimens of *L. mytiloides*.

"Regarding the age of this fauna I want to speak guardedly, for we have not been very successful in determining horizons in the Coal Measures by means of invertebrate faunas. The fossil plants seem to be much more reliable. As you observe, the list of species show essentially the same fauna at the only two localities where a fauna of any size was obtained. The invertebrates therefore afford no evidence favorable to subdividing these horizons into more than a single group. The species both as individuals and assemblages are such as are common in the coal bearing strata of Kentucky, Illinois, Iowa, etc., and in a general way indicate the same horizon for the coals of Michigan. This is not very definite, however. The age indicated is certainly older than the Upper Coal Measures of some writers, older than the Nebraska City beds of Kansas, for instance (See Meek's Pal. Eastern Nebraska, etc.). David White

thinks the plants indicate Upper Pottsville, if I am not mistaken. We have very scanty *faunas* from the Pottsville and I have no reason to contradict his determination."

The Lingula shale has also been found,—identical in appearance, above the coal (with a *Discinisca*) at the Valley Coal Mining Company shaft, at the Bay No. 2, at the Wenona Air Shaft and at the Monitor, in all cases as I take it just above the Upper Verne Coal, as it is also at the Michigan Standard Mine. It has been identified at Grand Ledge and on the Rifle River. The richer fauna which occurs just over the lower coal of the Michigan Standard, the lower Verne, in a black bituminous shaly limestone, has also been identified over the coal of the Amelith Shaft of the Pittsburg Co. Rominger reports similar fossils from Jackson (p. 127) and Williamston (p. 135), and again over the upper coal at Corunna (p. 138). Dr. Girty we see does not feel that these species are sufficient for close correlation, and it is well to remember that all the Lingula shales may not be at the same horizon though I am inclined to think it pretty persistent.

Both horizons are at times very close together, for instance in some parts of the Michigan Standard Mine, where the two coals run together toward the east. As Dr. Girty says, there is no indication of more than one horizon in the shells, which indicate quite clearly a marine or brackish fauna associated with those Verne coals. One cannot help being reminded of the upper and lower Mercer coals of Ohio. It is generally noticeable, also, that of the two coals associated with these fossils the upper is darker, less bright, with more charcoal and less pitchy layers, and though there are some sulphur balls it has less sulphur as a whole than the lower more lustrous coal, which contains more sulphur. All these facts indicate that most of the fossils come from one persistent not thick zone, that of the Verne coals.

The plant remains have been submitted to Mr. David White of the U. S. Geological Survey, who has been making an especial study of the remains of this epoch. He reports as follows:*

*The fossil lists returned by him are:
STANDARD MINE, SAGINAW.

1. *Sphenophyllum bifurcatum*, Lx.
2. *Neuropteris*.
3. *Calamites ramosus* Artis.
4. *Stigmaria verrucosa* (Martin Mill.) *S. acoides* (Brongn).
5. *Caulopteris* indet.
6. *Sphenophyllum cuneifolium* (Sternb. Tefl) old form *S. Sarsipofusolium*.
7. *Calamites* sp. indet.
8. Fragments of some fruit (*Cardiocarpon*?).
9. *Asterophyllites* cf. *longifolius* Sternb. (hardly determinable).

"These very incomplete and very fragmental floras interest me greatly, both on account of the fact that hitherto I have never seen else than *Calamites* (of little stratigraphic value) and *Stigmaria* from the coal measures of your state, and by reason of the clues they furnish us to the age of the coals mined at the above named points.

"I have not had time to search for data on the relative positions of the coals or as to their group correlations. From the characters of the little flora I conclude that it can hardly be later than the Lower Kanawha in West Virginia, of the Brookville coal in Ohio and Pennsylvania. In fact, notwithstanding the small number of species I am strongly disposed to regard the plants from the Standard Mine as Pre-*Allegheny*, or at least older than the Brookville coal. On the other hand, they are not older than the Sharon coal.

"The little flora in the nodule from the Owosso Coal Co. points strongly to a place in the Upper Pottsville, i. e., the *Sewanee* zone. There are not enough species to tell whether it is so low as the Sharon coal. I would suggest a comparison of the horizon with the Mercer group. It is not likely to be higher than the group if so high.

"From the above you see that although the material is very fragmentary and the species are few, they indicate for the coals, at

10. *Lepidodendron obovatum* Sternb.
GRAND LEDGE.

"The two fragments from Grand Ledge represent the same old early forms. *Sphenophyllum cuneifolium* (Sternb.) Teil." These are from the north pit of the sewer pipe works, near the level of the upper coal, the upper Verne? From the south pit as reported by the engineer of the works, Dr. F. H. Day, of Lansing, has in his collection.

19. *Lepidodendron lycopodioides* Stb. branchlets with *L. obovatum* Stb. bolsters.
- Cordaites borassifolius* (Stb.) Ung. fragments and *Cardiocarpon Cuyahoga* (D. W.)
20. (6) *Neuropteris flexuosa* Stb., close to European type.
21. (16) *Neuropteris* cf. *Harrieti* D. W. (*N. rarinervis* group) with *Asterophyllites* Sp.
22. *Diplothmema* Sp.
23. *Lepidodendron obovatum* Stb.
24. *Pseudopteris* (?) or *Marlopteris* (?), not enough for determination, for obscure nervation."

OWOSSO COAL CO.

I would like to suggest that good material, showing a much greater variety of species might be obtained by splitting off the more shaly external contacts of these nodules. The one which retained the contact shaly layers revealed.

1. *Cordaites*, probably *C. Robbii* Dn.
2. *Cardiocarpon orale* Lx.
3. *C. bicuspidatum* Sternb. var. *ohioense* D. W.
4. *Marlopteris* sp. cf. *inflata* (Newb. Mss.).

ST. CHARLES.

The following forms are from the various shafts at St. Charles, and almost all from that of the Michigan mine (Black Pearl Coal), and immediately above or below the lower coal, the Saginaw seam. A similar *Lepidodendron* flora is found at the shaft of the St. Charles Coal Co., above and in the splits of the coal.

1. *Lepidodendron modulatum* Lx., St. Charles.
2. *Lepidodendron dichotomum* Stb., St. Charles.
3. *Lepidophyllum cultriforme* Lx., St. Charles.
4. Macerated fragments of plants with spores and slickensides resulting from collapse of some soft body, probably the fleshy envelope of a fruit.
5. *Calamites* cf. *cistriformis* Stur., with *O. Suckowii* Brongn.
6. *Lepidophyllum cultriforme* Lx. Black Pearl Shaft, St. Charles. This is an old type.
7. Axis of *Lepidostrobus* cone probably belonging to the same species.
8. *Lepidostrobus*, apex of, probably belonging to the same species.
9. 12 and 18. *Lepidodendron ophiurus* Brongn.; St. Charles.
10. 13 and 15. *Lepidodendron rhombicum* Stb. (*L. lycopodioides*) Stb., St. Charles.
11. *Lepidophyllos?* decorticated and undeterminable. St. Charles.
12. 17, 18 and 25. *Stigmaria verrucosa* (Mart) S. A. Mill. main segment.
13. *Pseudopteris?* cf. *obtusiloba* (Brongn) Lx., J. H. Somers. No. 2 Shaft, St. Charles.

whose horizons they occur, a very low place in the coal measures; probably in the Sharon or Mercer groups for the nodules, while the Standard fossils seem to belong below the Homewood sandstone."

Dr. White also suggests a comparison of the Grand Ledge coal with the Mercer coals. I had already incorporated in the Mss., before receiving his letter, a comparison of the Verne coals with the Mercer coals, and all the evidence goes to show that the Grand Ledge coals correspond to the Verne coals.

The following correlation table may be of service, remembering that the Michigan correlations are very hypothetical as yet. But in a general way I assign the mines as follows:

Upper Verne: Wenona and Handy Bros., upper part; Central, seam not worked; Michigan Coal and Mining, seam now worked; Valley, Monitor, Bay, Wolverine(?), Verne, upper part; Owosso Coal Co., Grand Ledge and Williamston, upper seam.

Lower Verne: Wenona and Handy Bros., lower part; Central, Michigan Coal & Mining, first seam; Amelith shaft; Corunna Coal Co., Sebewaing; Grand Ledge, coal mainly worked; Williamston, Jackson.

Middle Rider, possibly the East Saginaw coals.

Saginaw seam, Pere Marquette No. 1 and No. 2, Standard, Saginaw, Chappell; Fordney, Riverside, Jamestown, Robert Gage, J. H. Somers, No. 1 and No. 2, Black Pearl, St. Charles Coal Co. The coals below this are not worked.

Regarding the abundance of plants in a broad and general way, White, speaking of the Pottsville, says (1891, p. 180): "The fossil contents are also different from those of any sandstones above, ~~the~~ here for the first time in descending the column of rocks do ~~the~~ And Sigillaria and the large Lepidodendra very abundant in ~~the~~ sandstones." Now at the Sebewaing, Saginaw and St. Charles coal mines I have noticed the prevalence of such forms and Calamites and the relative absence of ferns, and Rominger* noted almost exclusively such remains and the Stigmaria or creeping stems of the same plants.

*Geol. Sur. Michigan, Vol. III, Pt. 1.

CORRELATION OF COAL SEAMS.

Pennsylvania.			Ohio.		Michigan.	Mines and Shafts.
District.	Pottsville.	Lykens Valley.	Earlier Names.	Newberry.	Orton.	Base of Coal Measures proper.
	Upper Intermediate Beds N and M	Twin coal.		Putnam Hill No. 4 coal, Brookville.	Lower Clinton.	
	Beds J, K, L.	Lykens Coal No. 1			Tionesta.	Upper rider coal.
	Upper Pottsville formation.			No. 3a. No. 3.	Upper Mercer Limestone. Lower Mercer Limestone. Massillon sandstone.	Lingula shale. Upper Verne coal or Monitor coal. Lower Verne coal.
	Beds H, I.	(Sewanee zone in Tennessee.) Lykens coals Nos. 2 and 3.	Conoquenessing Sandstone.	No. 2.	{ Wellston Hill. Jackson Hill. Quakerstown.	Middle rider.
	Lower Intermediate Zone.				Massillon sandstone.	Sandstone.
	Beds E, F, and G.					
	Lower Pottsville.		Sharon conglomerate.	No. 1 Briar Hill, Massillon, Jackson.	Sharon coal. Sharon conglomerate.	Saginaw coal, Saginaw and St. Charles mines
	Bed D	Lykens coal No. 4. Brookside.				Lower rider.
	Bed C	Lykens coal No. 5. Big bed.				Lower coal.
	Bed A and B.	Lykens coal No. 6.				(Lower beds toward the center of the basin.)

Seral or Pottsville Conglomerate.

In regard to this matter of the predominance of the rush and tree like forms of the lower coal measures we might cite many authorities. For instance, even over in Germany Geinitz divides the coal measures into three groups, which are, beginning at the top:

(1) Strata where ferns prevail: Upper coal measures.

(2) Strata where *Annularia* prevails,—a form which has a whorl of leaves around the stem, and *Calamites*,—rush-like form: Middle coal measures.

(3) Strata where *Sigillaria* prevails, Lower coal measures.

Finally there is a certain similarity in stratigraphy or mode of occurrence, for we find that the law holds for the Michigan coals as well as for the lower coals in general, that they occur in elongate local troughs, probably running each one in a general way toward the center of the basin, but as a whole occurring in a belt parallel to the old shore line and the margin of the basin.

The coal as it occurs in Sebewaing, at Corunna and at Jackson, seems to occur in troughs which are longest east and west or northwest. For instance we find that in the Woodville, the coal rose and ran out toward the Michigan Central track to the southwest. We find similar phenomena noted on other maps of Jackson coal mines. The trough of coal on Sec. 7, Jamestown, near Saginaw, also seems to follow this rule.

Pittsburg coal shaft at Amelith is said to be connected with the Bay Coal No. 2.

The Pere Marquette Mine No. 1 is understood to drain into the Saginaw mine, but to be separated from the Standard to the southwest by a sandstone bar. On the other side it is not far to the northeast before this particular seam plays out.

The directions of the troughs are, however, quite variable, and we cannot yet lay much emphasis on this rule in Michigan. When we turn to the other States we find the evidence more decided. Prof. Sperr says of the lowest Ohio coal, the Sharon and Massillon that it lies in troughs.

Orton describes it as follows:*

"It always lies upon an uneven floor in basins of comparatively small extent. The area of but few of these basins reaches 200 acres of unbroken coal.

"It is everywhere a seam of 'swamp' and 'hills,' the latter rising

*Ohio, 1884, p. 154.

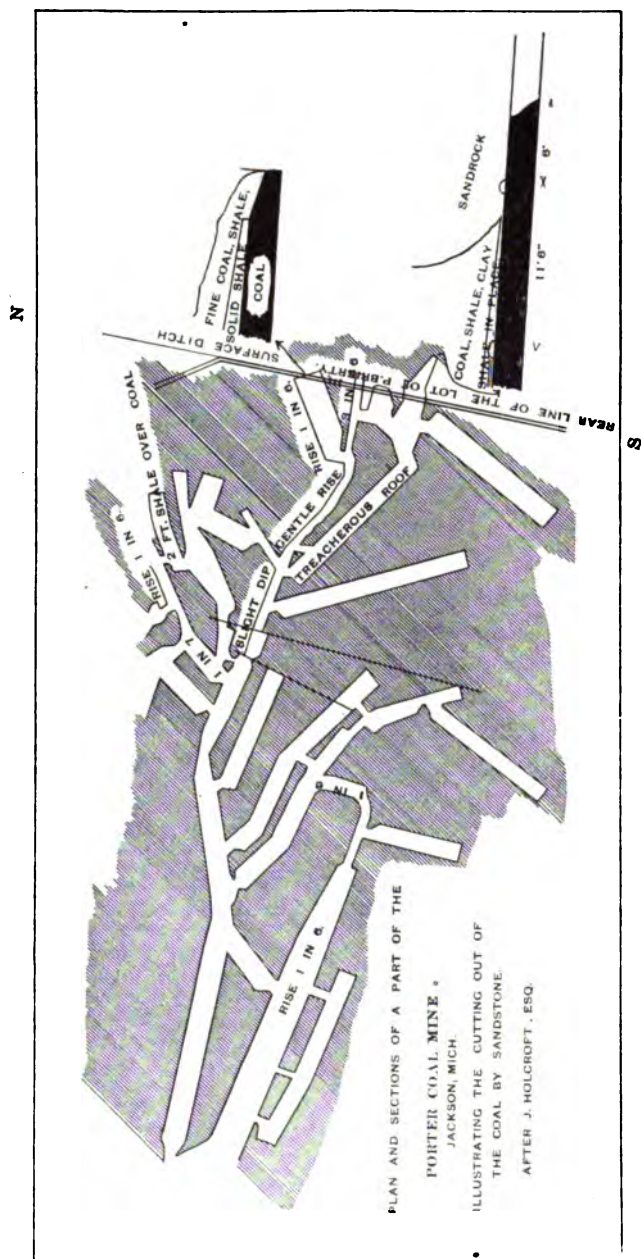


Fig. 5. Plan of part of the Porter Coal Mine, showing irregular mining following trough and stopped by a wasbout or drift filled channel.

20, 30 or even 40 feet above the lower and more productive portions of the seam. In ascending these hills the coal rapidly loses height as a rule, and frequently disappears.

(p.775.) "The Massillon coal occurs in lenticular areas of 30 to 70 acres, thickest at the center or axis of the swamp."

Again Bain and Leonard say (preliminary abstract of a paper before the Geol. Soc. Am., Aug. 25, 1898):

"The lower coal measures of the western interior field are marked by non persistence of strata. The upper measures are more regular. Between the two is a series partaking of some of the characteristics of each."

The same observation is made of the Indiana fields by Ashley in the 28th Annual Report, pp. 89 to 90.

And finally White remarks (1891, p. 180):

"The coals of the Pottsville series are persistent and valuable only around the margins of the Appalachian coal field."

It remains to be seen how far the coal strata of the center of the Michigan basin will show marks in their stratigraphy or plants of any later origin.

The two Verne coals may be traced, partly by stratigraphic comparison of record after record, partly by their chemical character, as coking coals, the lower one sulphurous, partly by their association with the *Lingula* shale, and calcareous beds full of marine fossils especially *Productus*, through the Bay county, Saginaw and Saint Charles fields, as I believe also in Owosso and Corunna, Williamston and Grand Ledge to Jackson.

If these are, as I believe, nearly equivalent to the Mercer coals, inasmuch as around Bay City they appear some 700 feet above the top of the Marshall sandstone, and may be traced more than half way to Midland with very little dip, it is quite possible that the 700 feet or more of strata above the base of the Parma sandstone at Midland belong wholly to the Pottsville formation, the extra thickness over sections elsewhere being produced by additions at its base. This is made more easy to believe, owing to the thick series of strata which Keyes has found elsewhere between the eocarboniferous limestone and strata of the age of the Pottsville.

Thus it seems to me at present most probable that the coal which occurs at about 136 feet around West Saginaw is at the same horizon as the coal at 85 feet around Sebewaing, and but little later

formed as the marginal floating bog gradually crept out over the surface of the comparatively shallow arm of the sea, whose bottom was slowly sinking, which was, however, yet more rapidly filling up.

Keyes has recently published a paper on the Trans-Mississippian coals and their correlation.*

The Pottsville formation and the best known part of the Michigan series correspond to his Des Moines series. The unconformity between them and the underlying eocarboniferous limestone, which he calls Mississippian, and possibly also some part of the lowest beds in the center of the basin, represents his Arkansan series.

*Engineering and Mining Journal, June 1, 1901.

CHAPTER IV.

ANALYSES AND TESTS OF COAL.

§ 1. Introduction and acknowledgments.

This subject which in the original report, issued in the *Michigan Miner*, was relegated to an appendix is treated more fully here. Numerous facts have accumulated in the meantime, the important series of tests made for us by Mr. H. J. Williams have been completed and we wish not only to help those who are having or should have analyses made to understand their value, but also to remove an impression which has been too prevalent, that Michigan coal is all of the same quality and that poor. Michigan coal is not all of the same quality and by no means all poor. Some of it (the Verne seams) is coking, some of it is not, some sulphurous, some (the Saginaw seam) not, and the heating power varies. Finally, Mr. Williams' results have a wider value, in fixing certain relations between heating power and analysis, which hold approximately true in Michigan at any rate.

I am indebted to Prof. F. S. Kedzie, of the Michigan Agricultural College, Lansing; Mr. H. J. Williams, of 161 Tremont St., Boston, Mass., for valuable help in the preparation of this chapter, and also for analyses and tests to F. F. Bradley of the Alston Manufacturing Co., A. N. Clark of the Alma Sugar Co., and C. H. Hilton, of the Agricultural College, Prof. C. A. Davis, of Alma, Geo. B. Willcox, M. E. of Bay City, and others.*

The following references will give the latest results and put one on the track of earlier works on this subject.

(1) Phillips, H. J. "Fuels, solid, liquid and gaseous, their analysis and valuation;" London, Crosby & Lockwood, 5 sh. This is practically reprinted in the "Engineering Chemistry" of the same author and publisher, 1894.

*Prof. Well of the Mechanical Department of the Agricultural College checked Plate II.

(2) Lord, N. W., and Haas, F. "The calorific value of certain coals as determined by the Mahler Calorimeter." Transactions of the American Institute of Mining Engineers, February, 1897 (Chicago Meeting), Vol. XXVIII, p. 259. In this same volume this paper is discussed by Wm. Kent and compared with earlier results, p. 946.

(3) Slosson, E. E., and Colburn, L. C. "The heating power of Wyoming coal and oil." Special bulletin of the Wyoming University, Laramie, gratis. January, 1895.

(4) Kent, William. "The calorific value of fuels," in Mineral Industry for 1892, p. 97, an annual published by the Scientific Publishing Co., New York, \$5.00, also in Vol. VIII, for 1899, pp. 124 to 129.

(5) Fritzsche Dr. P. "Die Untersuchung und Bewerthung der Brenn stoffe," Leipzig, 1897.

(6) Willcox, Geo. B. M. E. "Coal analyses—Their Objects and Uses." Michigan Miner, Vol. No. 4 (March 1, 1899), p. 19.

(7) Hale, R. S., and Williams, H. J. "The calorific Power of Weathered Coal." Trans. Am. Soc. of Mech. Engineers, December, 1898, Vol. XX, No. 798. Carpenter.

(8) Kerr, C. V., Trans. Am. Soc. of Mech. Engineers, Vol. XXI, No. 841, December, 1899. "The Berthier method of Coal Calorimetry."

(9) Christie, W. W. Trans. Am. Soc. of Mech. Engineers, Vol. XIX, No. 765, December, 1897, Boiler tests: Classification of data and plotted results.

(10) Hilton, C. H. "Sulphur and Iron in Michigan Coal." Michigan Miner, Vol. II, No. 9 (August 1, 1900), p. 9.

(11) Report of Committee on Revision of Standard Coal for Conducting Steam boiler trials, Vol. XXI. Transactions, Am. Soc. of Mech. Eng., No. 827 (December, 1899), and Discussions of same, No. 828.

(12) A new coal calorimeter by R. C. Carpenter; same transactions (June, 1895), No. 653.

There are also papers in Mines and Minerals, etc.

For the sake of those who have the works accessible, we may note that in the tenth census report (Gooch, Vol. XV, p. 775), and in the State Geological Survey reports, are many analyses, etc. (e. g. MM. of Pa.; Ohio, 1870, p. 236; Illinois, 1886, Vol.; Arkansas, etc.)

§ 2. Methods of testing.

Coal is principally used for producing heat. Its heat is mainly used for producing steam, and as thus used, the quality of the coal is naturally measured by the amount of water which it will convert into steam. In order to make this a definite quantity we must specify, however, how hot the feed water is, how hot the steam is and what the barometric pressure is. These will vary in different tests and reductions must be made accordingly, which are briefly noted below but are described more fully in mechanical text-books.

Whatever method of testing and of stating the results thereof is used, the results will be most easily understood by comparing them with some coal with whose behavior and quality one is familiar. For this reason, we have included in the reports of the tests, those upon a number of coals mined outside the state, but commonly used within it, so that the results may be interpreted by comparison with them.

The methods of testing are as follows:

(1) Direct boiler tests, in which the results are stated in pounds of water evaporated into steam, per pound of fuel or per pound of combustible. The latter is generally obtained by subtracting the amount of ash,* and properly also moisture from the coal.

These are often tests of the boilers as well as of the coal.

(2) Tests of the coal, obtained in the instruments known as calorimeters, in which the amount of heat given off in burning a quantity *is determined* by absorption of the heat in water and measuring the *rise* produced. The results of these tests are stated in calories, i. e., *the* number of units (kilograms) of water which one unit (kilogram) of fuel will raise 1° centigrade, or in British Thermal Units (B. T. U.), i. e., the number of units (pounds) of water which one unit (pound) of fuel will raise 1° F. It is supposed to take 965.7† of the British Thermal Units to convert a unit of water at boiling point, into steam of the same temperature under average barometric pressure at sea level.

Pure carbon is supposed to give from 8080 to 8140 calories, that is 14,544‡ to 14,652.2 B. T. U. so that one pound might convert 15.1 to 15.2 pounds of water already boiling, into steam. Under ordinary circumstances of feed waters, etc., about half that amount per pound of combustible is obtained.

*If the coal contains much oxidizable iron, etc., this may give too low percentage of combustible.

†Or as 1 calorie = 1.8 B. T. U., 536 calories. See Plate II.

‡Fabre & Silberman, 14,544; Berthelot, 14,647.

(3) The heating power may be very closely computed from what is known as an ultimate analysis and Dulong's formula, which is explained below, gives as good results as any:

(Heating power in B. T. U.) = $146 \times \% \text{ carbon} + 620 \times (\% \text{ hydrogen} - \frac{1}{8} \text{ oxygen}) + 40 \times \% \text{ sulphur}$.

(4) The heating power has also been estimated in various ways from what is known as a proximate analysis, but the formula which seems to give as good results as any of them for our Michigan coal* is, heating power in B. T. U. = $146.6 (\times \% \text{ combustible}) + 40 (\times \% \text{ sulphur})$.

(5) The heating power is sometimes computed from the reducing or deoxidizing power of the coal. This is known as Berthier's method and for a unit of fuel we recommend for our Michigan coals to apply a formula which I have derived on a following page: Heating power in B. T. U. = $423.4 (\times \text{amount of lead reduced}) \times 650$.

The last terms in these last two formulæ are fairly small, and the formula practically implies that the heating power is nearly proportionate to the $\%$ of combustible regardless of the relative proportions of fixed and volatile carbon. This is not accepted for coals in general and I do not wish to propose to extend these formulæ, except for our Michigan coals or so far as tests confirm them.

We will now proceed to consider these various methods of testing in detail after we have first considered the very important question how we are to get as fair a sample as possible of the coal for testing.

§ 3. Sampling.

A single lump is quite likely to be misleading. The heavier sulphur, slate and dirt tend to accumulate at the bottom of a pile, and in the finer stuff or slack. It requires some care to get a fair sample. Samples from well drillings are usually mixed with more or less clay from above. If that is washed out, as it usually is, it is nearly impossible not to wash away at the same time a certain amount of the pyrite (sulphur and ash), which occur in the coal. "At least five pounds of coal should be taken for the original sample, with care to secure pieces that represent the average, say the A. C. S. committee." In taking samples of worked seams, my own practice is to take about 25 pounds, evenly distributed from top to bottom of the worked seam. Very commonly in Michigan

*Provided the moisture is thoroughly driven out.

immediately above the main seam, is from 3 to 8 inches of poorer "bone coal," "cannel coal" or "slaty coal," sometimes improperly called black jack. This and the larger masses of pyrite will be kept out of the coal in mining and shipping, so far as possible, but more or less gets in especially in the run or slack. Care should therefore be taken to say whether these and slate partings were included in the sample or not. Thus the coal as shipped may possibly be somewhat better than a fair sample of the seam taken as above. It may also be poorer. My large samples were sent to H. J. Williams. He has some very ingenious arrangements for getting a true fractional sample. In general principle the material is run through a crusher and falls upon a sloping screen the bars of which are, however, hollow upwards and catch and conduct to one side a certain percentage of the material. The material which Mr. Williams did not use was returned to me and then fractioned very much as described by Fritzsche, and is preserved in sealed glass jars containing half a pound to a pound, for distribution. The samples when shipped to Williams and back again were not, however, in tight jars, but in stout paper bags inclosed in cloth sacks, and then boxed or barreled, so that there was opportunity to dry, and lose all superficial moisture.

Mr. C. H. Hilton's analyses show some desiccation that came since or in the later finer grinding of the material. The material thus preserved in jars is about pea or rice size.

The method of sampling recommended by Fritzsche* is as follows:

"Sampling is best done by an experienced hand as follows:

"From every cage or bucket of coal which is to be tested a shovel full is thrown into a separate bin. At the end of the sampling, the large pieces of the sample (which will weigh from 50 to 100 lbs.) are broken to nut size and the samples well mixed on a large floor or plate and the top of the pile pressed flat. Then with a smaller shovel, a narrow section is taken straight across and another at right angles. This smaller sample of from 5 to 10 lbs. is best sent in a tin lined chest to the analyst, who crushes still further and proceeds as above indicated two or three times over to get a good average sample of 300 grams weight, in pieces the size of a millet seed. This sample is kept in a glass jar with tight glass stopper and used for determination of moisture after a quarter of the same is taken off in the same way and crushed to a fine powder and put in a separate bottle, for the rest of the analysis."

*1897, p. 48.

§ 4. Determination of moisture.

The first step in either an ultimate or proximate analysis is the determination of moisture. This determination is also commonly made in calorimeter* and other tests. For the moisture in a coal obviously does not help its heating power, and in the same fuel is liable to a good deal of variation depending upon the time it has been kept and the surroundings.

In this determination a sample of coal is first weighed, and then thoroughly dried. Gooch dried his sample over sulphuric acid 48 hours, weighed it, and then suspended it over water, but not in touch with it, 48 hours more and weighed again. The more common method is to heat nearly to boiling for about an hour (Phillips, and Lord and Haas, one hour at 100° to 105°C., Williams 45 to 60 minutes at from 105° to 107°C.), and the loss of weight is given as moisture or H₂O. To get comparable results the same methods must be employed. Probably it will be best to follow the rule of the A. C. S. committee: "Dry one gram of coal in an open porcelain or platinum crucible at 104° to 107°C., for one hour, best in a double walled bath, containing pure toluene, cool in desiccator and weigh covered."

Prof. Kedzie believes that more uniform results are obtained by drying the finely powdered material in vacuo over sulphuric acid.

It would be more accurate, but more expensive to collect the moisture and weigh it.

Kent has called attention to the fact that on heating the coal the weight decreases to a minimum, somewhere about 250°F., and then increases slightly (as the pyrite oxidizes?), and no loss of volatile matter occurs until about 350°F. His results have been confirmed by Carpenter and F. S. Kedzie.

This moisture is not merely wetness on the outside of the coal, although such would be included if there. But the samples which were sent to Mr. Williams, were so packed that they had a good chance to lose any superficial wetness, and after being returned from him were stored for sometime in a dry room, before being divided and sealed. Mr. Hilton remarks of them, that even then, while "the coals are to all appearances perfectly dry, yet when they are subjected to a temperature of 100°C. for half an hour they lose 5 to 10 per cent of their weight." So also Mr. Thomas Pray remarked regarding the amount of moisture in the sample whose

*Especially in using the Parr Calorimeter, see p. 73.

analysis he furnishes (Table I, Nos. 3 and 4), that it was not superficial moisture. Almost all of the Michigan coal is under strong hydrostatic pressure, except that around Grand Ledge. Coal is also somewhat hygroscopic. The lightness of the coal seems to be partly due to the moisture.

Especial care must, therefore, be taken to drive off all the moisture, and I think that many analyses of Michigan coal have failed in this respect. In boiler tests, for instance, it has been a common practice to set a pan of the coal not over three inches deep on the hottest part of the brick work for twelve hours. This method will not be at all satisfactory for Michigan coals. It gets rid of the "surface" or "accidental" moisture, but not the "characteristic" moisture, which may be sometimes reabsorbed from the air after being driven off by gentle heating, and is high in our Michigan coals generally.

In some coal high in sulphur and clay there is reason to believe that the low moisture returned is an analytical error, as will be later explained.

§ 5. Determination of ash.

Even in the common use of boilers it will be found of great practical benefit from time to time to make a trial run under average conditions, weighing the amount of feed water and coal used and of ashes removed, leaving the plant as nearly as possible in the same condition as found. Some results of tests of this character at the Lansing Municipal plant are given below (pp. 72 and 73). Tests of percentage of ash are almost invariably made in connection with any heating tests as well as ultimate and proximate analyses.

The A. C. S. recommend determining this from the sample left after determining moisture, thus: "Burn at first over a very low flame with the crucible open and inclined till free from carbon," that is, until further burning makes no alteration in weight. If properly treated this sample can be burned much more quickly than the dense carbon left from the determination of volatile matter.

The further determination of the constituents of ash is like the analysis of any rock, and several analyses are given by Phillips.

A complete analysis of ash is quite expensive, and the components determined are those usually determined in rocks, SiO_2 , TiO_2 ,

Al_2O_3 , Fe_2O_3 , (originally either sulphide, carbonate or oxide of iron) CaO , MgO , Na_2O , K_2O , CO_2 , P_2O_5 (important in cokes for iron smelting) and H. J. Williams analyzes the ash for sulphur at any rate, in order by subtraction to get the volatile sulphur. It is well to analyze the ash in case the coal is to be used in Portland cement manufacture.

The oxidation of the iron and the partial separation of the CO_2 , where the ash is largely CaCO_3 , as Bradley reports to be true of a St. Charles sample, and Mr. Hess of a sample from the Corunna Coal Co., introduce errors in the process of burning, making the ash more or less than the substance from which it was derived in the coal, but they are probably quite small, though I have seen crystals of gypsum on the surface of the Michigan coal, and veins of calcite and anhydrite. In very sulphurous coals as in No. A6 it may be apparent that if all the sulphur came from FeS_2 , all the ash must have too. For a given per cent of sulphur present in marcasite FeS_2 we shall have $\frac{1}{8}$ as much iron or $10 \div 8$ as much Fe_2O_3 in the ash. The ash will be greater than it should be by an amount equal to $\frac{3}{8}$ of the % of S. If half the sulphur remained after driving off the volatile combustible, the per cent of fixed carbon found by subtracting the % of ash from the residue left after driving off the moisture and volatile carbon will be $\frac{1}{8}$ of the S too large.

For instance in Williams' analysis of the Michigan Standard Coal Mine below (No. A9), if we suppose, as Hilton's work makes likely, that the volatile S is all in pyrite, this must have contained 4.98% Fe, equivalent to $(4.98 \times 10 \div 7)$ 7.11 Fe_2O_3 in the ash. Hence the ash (8.26%) found by analysis was almost wholly iron oxide. Instead then of the coal having an analysis of 6.09% moisture, 39.59% volatile combustible (including $\frac{1}{8}\text{S}$) 46.06 fixed carbon, and 8.26 ash, it should really be, supposing that the S were half driven off with the volatile matter, 6.09% moisture, 36.75% volatile hydrocarbon not including S, 10.66% pyrite, 1.15 ash and 46.35 fixed carbon.*

Hilton's work† indicates that the iron and the volatile sulphur are practically so closely connected that one may be inferred from

*In some older forms of proximate analyses the sulphur was subtracted from the volatile matter or in part from the volatile matter and in part from the fixed carbon, half from each by some chemists or 60% from the volatile matter and 40% from the fixed carbon. This is not at all to be advised, since the proportion of sulphur which goes off with the volatile matter is uncertain, and varies not only with slight differences in manipulation, but also according as there is more or less of sulphur as sulphates in the ash.

†Reference on page 52.

the other, since they are in the same proportions as in pyrite, i. e., 7 of iron to 8 of sulphur. Thus an analysis for iron, one of the most simple and rapid of chemical operations, would be very nearly as instructive as the much more troublesome test for S. His results are given in Table D of analyses below and are shown graphically in the figure accompanying.

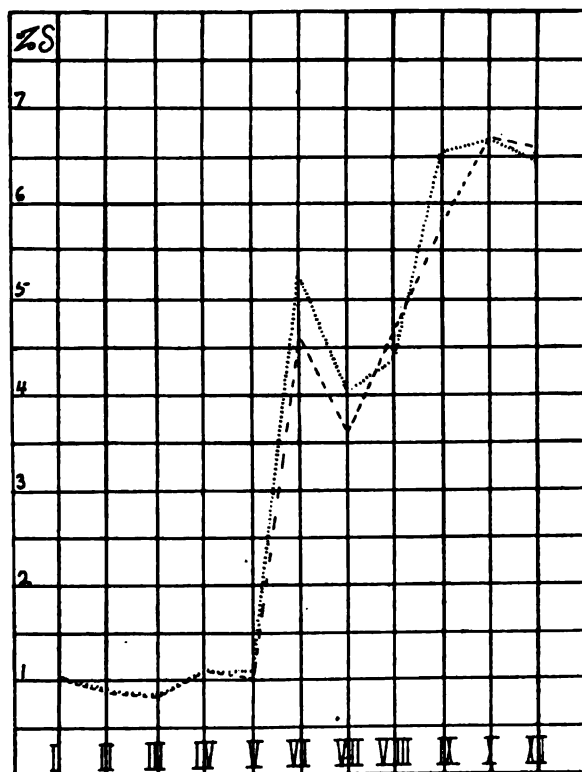


Fig. 6. After Hilton, illustrating the connection between the sulphur and iron in the coal analyses of Table D. The line with dashes connects the percentages of S directly determined, the dotted line, the percentages of S computed as $8 \div 7$ of the iron.

§ 6. Determination of sulphur.

There is one constituent of so marked effect on the quality of the coal that an especial test for it is, and should be usually made, even in a proximate analysis, unless the method above suggested of estimation from the iron may in some approximate work prove satisfactory, and that is the sulphur.

Usually the coal containing the sulphur is burned in a closed

vessel or combustion tube with one or another oxidizing agent to ensure complete oxidation to sulphates, and no escape of gas, and then the resultant amount of sulphates determined. If the amount of volatile sulphur* (sulphur combined as pyrite) is required the amount of sulphur or sulphates in the ash may be found and then subtracted from the total sulphates, but as the analyses show (Table A) the sulphur of the ash is usually only two or three tenths per cent.

This is the process adopted by Williams, who uses the method of analysis usually followed, known as Eschka's, thus described by Fritzsche:

"Weigh 1 gram of the same coal powdered in a platinum boat holding 30÷50cc. Add 1½ grams of previously prepared mixture of 2 parts sodic carbonate and one part of magnesia, thoroughly mix with a platinum spatula and heat the crucible over a Bunsen burner turned down to a small flame so that only the bottom of it is faintly red, one hour, frequently stirring with a platinum rod. The reagents should be free from sulphates, which is frequently not the case, especially with the magnesia, even though it is bought as chemically pure. If the amount of SO_3 in the magnesia is known, a corresponding correction may be made in the result. To make sure of the complete oxydation of the organic matter as well as any sulphides that have been formed, add to the partially cooled contents of the crucible a few decigrams of finely powdered ammonium nitrate NH_4NO_3 , and heat once more in a covered crucible. Shake out the contents when cool into a beaker, wash several times with distilled water, and free any small quantities that stick to the vials, add to the wash water about 100cc distilled water to the beaker and boil about ten minutes. Put the cooled off solution with that which is undissolved in a 250cc measure glass. Fill up to the mark, mix and use 200cc of the filtered solution to determine sulphuric acid as usual."

Williams oxidizes with bromine in the presence of a little HCl , and precipitates with BaCl_2 forming BaSO_4 .

13.789% of the $\text{BaSO}_4 = \% \text{S}$.

Fritzsche says that it is decidedly not advisable in order to insure complete oxidation that the sodic carbonate and magnesia be brought to fusion for some minutes, since in that case the silica of the ash is more or less dissolved and must be removed with much loss of time before the sulphuric acid determination can proceed.

Mr. Hilton proceeded as follows, using a modification of Eschka's method:

*This will not be the same as the amount of sulphur volatilized in the volatile matter necessarily, for there is likely to be some fused pyrite left in the coke.

"A weighed portion of coal (1-1.5gr.) is intimately mixed with five times its own weight of sodium carbonate c. p. and placed in a flat bottomed platinum dish. The sample thus prepared is placed in a muffle, which, though hot, is still black. The furnace is so regulated that in half an hour's time the muffle will have reached a clear cherry red color. This degree of heat is maintained for another half hour, at the end of which time it is found that all the sulphur as well as all the carbon is entirely burned. The sulphuric acid displaced a portion of the carbonic acid of the carbonate, thus forming a soluble sodium sulphate. The remainder of the process is identical with Eschka's method.

"The sulphuric acid in the ash is made soluble by boiling the ash in a strong solution of sodium carbonate. The determination of the sulphur is then the same as in the whole sample."

Fritzsche also describes a method by which the combustible sulphur may be determined directly, the combustion taking place in a current of oxygen passing through a tube in which the coal lies in a platinum boat and is heated, the products of combustion being caught by being passed through two Peligot tubes filled with bromine and dilute HCl (or as he suggests H_2O_2 may be used if it can be obtained free from sulphuric acid). At the end when no more brightening glow of combustion can be obtained from the coal, the contents of the two tubes are thoroughly washed into a beaker, heated until bromine fumes disappear and into the hot solution of about 150 to 200cc, 2cc of a 10% BaCl_2 solution added. After a short boiling the precipitate is allowed to settle and the liquid above poured through an ashless filter, water is added to the precipitate and boiled again, and the precipitate brought upon the filter and washed with hot water until the wash water ceases to react for chlorine. The moist filter paper is put into a platinum crucible (folded together a little) and then burned to whiteness over a large Bunsen flame in a weighed open crucible. If the amount of BaSO_4 is but small the amount of the sulphate, which is reduced by the organic matter of the filter paper, is completely oxidized again after a short heating. If the precipitate is large and lumpy it may be well to moisten with some drops of ammonia sulphate c. p. and heat again.

§ 7. Ultimate analysis.

The ultimate analysis consists in the determination beside the ash, sulphur and moisture already described, of the carbon (not including the carbon present as CO_2 in the ash), the hydrogen (not including that in the moisture), the nitrogen, and (*by difference generally*) the oxygen.

The coal is burned in a glass combustion tube as in the determination of volatile sulphur, in an atmosphere of pure oxygen, with copper oxide and lead chromate, and the products of combustion are collected separately, by being passed through a series of tubes: carbon as CO_2 absorbed by KOH , hydrogen as H_2O absorbed by CaCl_2 or H_2SO_4 . Nitrogen is determined volumetrically or by Kjeldahls' method, or the total acid product may easily be obtained in connection with the Bomb calorimeter test described below, and is sometimes ascribed to nitric acid. This would be quite inaccurate for our sulphurous Michigan coals, but if the sulphur is known the nitrogen may be computed.

Such an ultimate analysis costs about \$15.00 or \$20.00 and the heating power can be computed from it quite closely by Dulong's formula, as discussed below. It is to be noted that since the oxygen is determined by difference, any error in the other determinations will be reflected in it. If, for instance, the determination of ash is too large* that of oxygen will be too small.

§ 8. Proximate analysis—volatile combustible.

In addition to the determinations of ash and moisture, only one further determination is used in what is known as a proximate analysis, that of the volatile matter or volatile combustible as it is called. The endeavor is to estimate the hydrocarbons with part of the sulphur or that part of the coal which makes gas.

Comparable analyses of volatile matter must follow the same procedure, as various times and temperature give varying products and varying amounts of residue.

The A. C. S. committee procedure is:

Place one gram of fresh, undried coal in a platinum crucible, weighing 20 to 30 grams and having a tightly fitted cover. Heat over the full flame of a Bunsen burner for seven minutes. The crucible should be supported on a platinum triangle with the bottom 6 to 8 centimeters above the top of the burner. The flame used should be 20 to 25 centimeters high and burning free, and the determination made in a place free from draughts. The upper surface of the cover should burn free, but the lower should remain covered with carbon. To find volatile combustible matter subtract the percentage of moisture from the loss found here, the residue, if coherent, is the coke.

*Through oxidation of the iron of pyrite, etc. If the earthy matter of the coal consisted largely of carbonates the error might be the other way.

Lord and Haas heated $3\frac{1}{2}$ minutes over a Bunsen burner, then $3\frac{1}{2}$ over a blast lamp. The difference between this and the ash is called the fixed carbon.

It is clear that a proximate analysis is but a series of weighings and heatings. Thus:

	Loss is	Residue is
First heating to a little above boiling (under 250° F.).....	moisture.....	dry coal
Second heating, seven minutes until the smoky yellow flame ceases.....	{ volatile..... combustible..	{ coke
Third heating, until there is no more loss.....	{ fixed..... carbon.....	{ ash

Practically, however, it is found best to find the moisture and ash from one sample and the volatile carbon from another, while the fixed carbon is estimated by difference. It is obvious that the sum of the percentage of the different components being always 100, if one is too large, for instance the ash, owing either to the fact that the coal was not completely consumed, or that the ash contained iron which was oxidized, then some other component like the fixed carbon must be too small.

The proximate analysis is much cheaper and simpler than the ultimate, and if a determination of sulphur is also made it may give us practically almost as much information as the ultimate. The heating power cannot be told from it quite so reliably in general, though from any one seam and district a formula may be obtained nearly as good, and as will be shown below, the formula,

Heating power in B. T. U. = 146.6 (total combustible; i. e., fixed carbon and volatile combustible) + 40 (per cent of sulphur), gives as good average results for Williams' analyses as Dulong's formula applied to the ultimate analysis.

§ 9. Nature of the volatile combustible or gas.

The volatile combustible consists as we have said mainly of illuminating gas together with certain impurities including much of the sulphur.

The hydrogen sulphide and carbon bisulphides, ammonia and other impurities of a tarry nature which are distilled in the volatile matter are deleterious to a fuel or illuminating gas, though of some value in themselves, and must be got rid of so far as may be. They cannot be eliminated entirely. To this end the sulphur is absorbed by quicklime, or by fresh ferric hydrate spread on saw-

dust, which recombines with the sulphur to form sulphide of iron once more.* It is common to estimate the purity of the gas by the number of cubic feet which will be purified by one bushel of lime. In Analysis I1 Pennock found per ton of 2,000 lbs. 19.16 lbs. of ammonia sulphate = .958% = $1.373 \times$ the percentage of ammonia; also 110 lbs. of gas tar = 5.5% and 10,600 cu. ft. of gas. According to Winchell the Jackson coal yielded 8,000 cu. ft. per ton of 2,000 lbs. and 30 to 40 bushels of coke.

The ammonia is used extensively in producing soda from salt by the Solvay process, and in domestic use. The gas weighs from half as much as air up, or about 30 cu. ft. to the pound.†

The following is a commercial report on a test of the Saginaw coal in gas production, made at the Keystone Tumbler Company, Rochester, Pa., in the Duff Continuous Water Sealed Gas Producers:

"Sixty-one tons of Saginaw coal operated the plant for six days continuously; no other coal used on the premises during the time of test.

"With Pittsburg coal, they used on an average of twelve tons every twenty-four hours to operate the plant, showing that sixty-one tons of Saginaw coal accomplished the same work as seventy-two tons of Pittsburg coal.

"At the end of the six days' run, there was less deposit of tar and gummy substance on the flues than is usual with local coal for the same length of time.

"There was less accumulation of clinkers and ash than with local coal for the same length of time.

"Comparison of Saginaw coal with best grade of Pittsburg coal, by analysis; from Pere Marquette No. 2 Shaft."

	Saginaw.	Pittsburg.
Moisture	1.98	.20
Fixed carbon	53.20	55.69
Volatile combustible matter	43.49	39.54
Ash .....	.97	4.05
Sulphur .....	.394	.52

Wuth & Stafford, who made the analysis, say:

"This is undoubtedly a good steam coal and we think it will do very well for producer gas. It requires a little different work from our Pittsburg coal and will take a little practice to find how to handle it."

They mean by this, that because of the high percentage of moisture, steam and air injected into the producers must be regulated differently.

*Ferric hydrate is a waste product from purifying brine and sawdust a waste product of lumber. So that although the quicklime process is the more usual one, one would think the latter process might be economically employed at some points in Michigan.

†For analyses of gas, etc., see Mineral Industry, 1899, Vol. VIII, p. 147.

BERTHIER'S METHOD modified. GRAMS OF LEAD <small>reduced from litharge</small> B.T.U. = 423.4 (Lead) + 632		COM-BUSTIBLE and HEATING -POWER B.T.U.=146 X % comb.	CALORIES <small>units of water raised 1° C.</small> <small>per unit of coal</small>	B.T.U. <small>British thermal units.</small> <small>—pounds of water raised 1° F.</small> <small>per pound of coal</small> 14000	U.E. <small>units of evaporation</small> 15 lbs. <small>of water turned to steam at boiling point</small>	EVAPORATION <small>from 100° at 70 lbs.</small>	HORSE -POWER <small>corresponding to U.E.</small>
30	90%				14	12 lbs.	0.40
				13000			
25	80%		7000		13		0.38
				12000	11		0.36
20	70%			11000	12	10	0.33
			6000		11		
15	60%			10000	10	9	0.30
			5000	9000	9	8	0.27
	50%			8000	8	7	0.24
			4000	7000			0.21

EQUIVALENT EXPRESSIONS for HEATING POWER of AVERAGE MICHIGAN COAL

EXPLANATION OF PLATE II.

This Plate is intended to illustrate the equivalences in various expressions for the heating power of the coal, and also the heating power to be expected of the average Michigan coals, if it contains a certain per cent of combustible, column 2, or a certain reducing power, column 1.

For instance we see that if the burning of a pound of coal can raise 11,000 lbs. of water 1° F., the burning of one gram of coal can raise about 6.10 grams of water 1° C. A pound of such coal can then turn 11.4 lbs. of boiling water into steam, or 9.9 lbs. if the pressure is 70 lbs. to the sq. in. This is equivalent to a third of a horse-power per hour. For each horse-power per hour therefore if we use coal of 11,000 B. T. U. grade we must use three (times a factor which depends on the efficiency of the boiler and engine and is usually not less than two) pounds of coal. Such a coal would be a very low grade one for a Michigan coal, containing only 76.3% combustible, i. e. 24.7% of moisture and ash. Michigan coals generally run 13,000 to 14,000 B. T. U., that is the combustible is near 90% and the amount of moisture and ash not far from 10%. A gram of such coal we see from column 1 should reduce not far from 30 grams of lead from litharge, while the lower grade (11,000 B. T. U.) coal should only reduce 24.5 grams, supposing it to have the average composition of Michigan coals.

The superintendent of the works where the test was made says:
"The coal is better than we get here.

"We are of the opinion that the coal is suitable for gas making purposes and that it can be used with economy.

"(Signed) H. L. DIXON,
"No. 3 Wood Street,
"Pittsburg, Pa."

It will be noted that while they speak of the "high percentage of moisture" in the body of their letter, the analysis shows much less moisture than many of our analyses, but on the other hand more volatile matter. This is almost certainly due to a difference in analytical treatment.

Of these so called impurities of the gas, the coal-tar matters have, however, a very considerable value in themselves. In one case I was informed that a company offered to pay all the expenses of altering a coking plant which was letting them go, and guarantee a good price for the coke product, finding their profit solely in the coal-tar matters.

§ 10. Coke.

The residue after driving off the volatile matter or gas, if coherent, is called coke. But, according to the time, quickness and severity of the heating and amount of ash will more or less of the carbon and sulphur be retained. The coke contains, of course, all the ash.

The most called for coke should be clear, bright, hard, open textured, with but little sulphur and phosphorus, especially for iron manufacture. Its porosity may be tested by weighing it dry and then when saturated with water.

I have seen some nice looking coke made as an experiment from the Wenona coal, and it will be noticed that Mr. Williams reports a number of the coals as the coking coals. The coals which are thus coking are not, however, the lowest in sulphur, but as Dr. Koenig has remarked, by proper handling a large part of the sulphur may be driven off, so that but little will appear in the coke. Ordinarily only about half of the sulphur is driven off, FeS_2 being changed to FeS . Tests have been made of the coke from a number of the Bay county mines. For instance, samples from the Valley Mining Company's shaft at Salzburg are reported to have yielded 39 bushels of coke per ton at the Bay City gas works. The coking coals seem to be the Verne coals.

§ 11. Heating power—practical test.

The full amount of heat that can be obtained from coal in a physical apparatus cannot be practically obtained under a boiler, where the combustion of coal is not perfect, as when there is incomplete combustion to CO, instead of CO₂, 11÷16 is lost. Also the gases escape hot and every per cent of moisture or of hydrogen burned to water in the coal that escapes as steam carries away much heat with it. The percentage of heating power actually realized depends not only on the coal, but on the perfection of the furnace draft and boiler. It is the highest where unburned air forms about one-third of the chimney gas, and has been found as high as 55% to 65% of the theoretically possible. For instance 7 Saarbruck coals which showed an average of 7,500 calories, i. e., should have evaporated 13.37 pounds of water theoretically, evaporated 8.17 practically (from and at the boiling point) and the heat was supposed to be distributed as follows:

	per cent.
Heat used in steam making	61.00
Ungenerated in combustible gases lost	5.5
Lost in hot clinkers and ash	1.5
Lost in hot products of combustion	5.5
Lost in smoke	0.5
Lost in evaporation of moisture	2.5
Lost in brick work	25.5
	<hr/> 100.00

We notice that the tests quoted by Mr. Willcox give similar results for the Michigan Coals, from seven to nine pounds actually evaporated, or from and at 212°F. from 9 to 12 pounds. And Mr. E. C. Fisher's test given below (p. 67) gives about 7 pounds actually evaporated, i. e., 8.63 lbs. per pound of combustible, or 59% of that given by Pennock's Calorimeter test, showing that the boiler was doing good work. The commercial evaporation is by convention fixed as the evaporation from a feed water temperature of 100°F. to steam of 70 lbs. gauge pressure. In Plate II we have the various methods of expressing heating power arranged in scale side by side, so that equivalent expressions may be seen at a glance. The commonest methods of expressing heating power are in units of evaporation, i. e., pounds of water changed to steam at a temperature of 212°F., or British Thermal Units, i. e., pounds of water raised one degree Fahrenheit. The tests of Mr. Edmond A. Edgerton, superintendent of the electric light and water works, Lansing, run 5½ to 9 pounds evaporated. We must remember that to fully estimate the heat obtained from coal we must know how

warm the feed water was and how many degrees it had to be raised to the boiling point. Again, the boiling point is not always 212°F., though it is popularly supposed to be so, but it is higher as the steam and atmospheric pressure increases. Finally, if the steam is superheated or contains moisture, there is more heat used there. There are, therefore, a number of corrections to be applied before results in different boilers under different conditions are applicable. For instance the coal that would evaporate 30 pounds of water per hour (one commercial horse power), the temperature of the water being 100°F. and the steam pressure being 70 pounds, would evaporate 34½ pounds of boiling water under atmospheric pressure into steam of the same pressure. Even then conditions that cannot be exactly figured out, the different adaptability of different grates and draughts to different coals, and subsequent varying loss in smoke and chimney gases, in brick work, clinker and half consumed ash, and the different experience of different firemen in handling different coals are so important that results must be taken with caution, and are mainly used in showing what coal gives best results with a given boiler outfit. For this purpose they are very valuable and should be widely used. If one coal is 10 per cent more efficient than another, it means more than 10 per cent discount in price.

The conduct of a complete boiler test is the work of a mechanical engineer, and is surrounded by a multitude of minute precautions detailed in papers in the Transactions of the Mechanical Engineers referred to, which cannot be repeated here.

The following report of a trial by E. C. Fisher of the comparative value of Saginaw and Hocking Valley coal is a good illustration of a boiler test. It will be noticed that the Saginaw coal used appears to be a trifle less efficient than the Hocking Valley pound for pound, but considerably more efficient at the prices quoted.

TEST BY E. C. FISHER, ON ONE WICKES' PATENT WATER TUBE SAFETY
STEAM BOILER.

Fuel—		Saginaw.	Hocking Valley.
Kind of coal.....			
Total amount consumed.....	Lbs.	6092.0	5806.5
Moisture in coal.....	%	5.5	5.
Dry coal consumed.....	Lbs.	5757.0	5518.06
	%	4.2	6.1
Total refuse.....	Lbs.	245.5	288.5
Total combustible.....	Lbs.	5511.5	5179.5
Dry coal consumed per hour.....	Lbs.	575.7	551.808
Combustible consumed per hour.....	Lbs.	551.15	517.95
Results of Calorimetric Tests—			
Quality of steam.....		.9925	.9927
Percentage of moisture.....	%	.75	.73

BOILER TEST—Continued.

		Saginaw.	Hocking Valley.
Economic Evaporation—			
Water actually evaporated per lb.....	Lbs.	6.93	6.99
Dry coal.....			
Water evaporated per lb. dry coal from and at 212° Fahr.....	Lbs.	8.26	8.32
Water evaporated per lb. combustible from and at 212° Fahr.....	Lbs.	8.63	8.87
Rate of Combustion—			
Dry coal burned per sq. ft. grate per hour	Lbs.	25.5	24.5
Dry coal burned per sq. ft. water heating surface per hour.....	Lbs.	.363	.34
Rate of Evaporation—			
Water evaporated from and at 212° per sq. ft. grate surface per hour.....	Lbs.	211.04	204.1
Water evaporated from and at 212° per sq. ft. water-heating surface.....	Lbs.	3.00	2.90
Commercial Horse-Power—			
On basis of 34.5 lbs. water evaporated per hour from and at 212° Fahr.....	H. P.	137.9	133.2
Builder's rating.....	H. P.	144.0	144.0
Cost in coal to evaporate 100 lbs. of water from and at 212° Fahr.....	Cts.	14 4-10	15 8-10
Cost of coal per ton (2000 lbs.).....	\$ & Cts.	2.25	2.50
Water evaporated from and at 212° per pound wet coal.....	Lbs.	7.80	7.91
Efficiency of boiler.....	%	71.10	

The following blanks, used by Prof. Weil of the Mechanical Department of the Agricultural College, show the numerous items which should be noted in an accurate test. The Committee of the American Society of Mechanical Engineers give two forms for a standard test of boilers, the longer including 88 items, the shorter 33:

Description of Boilers for trial at.....
of (No. and type).....
Date.....
(a) Type of boiler.....
(b) Diameter of shell.....
(c) Length of shell.....
(d) Number of tubes. } Vertical.....
 } Horizontal.....
(e) Diameter of tubes.....
(f) Length of tubes. } Vertical.....
 } Horizontal.....
(g) Diameter of steam drum.....
(h) Length of furnace.....
(i) Width of furnace.....
(j) Kind of grate bars.....
(k) Width of air spaces.....
(l) Ratio of area of grate to area of air spaces.....
(m) Area of chimney.....
(n) Height of chimney above grate.....
(o) Length of flues connecting to chimney.....
(p) Area of flues connecting to chimney.....

Governing Proportions.

(a') Grate surface.....
(b') Heating surface. } Water.....
 } Steam.....
 } Total.....
(c') Area of draught through or between tubes.....
(d') Ratio of grate to heating surface.....
(e') Ratio of least draught area to grate.....
(f') Ratio of least draught area to total heating surface.....
(g') Water space (cu. ft.).....
(h') Steam space (cu. ft.).....
(i') Ratio grate to water space.....
(j') Ratio grate to steam space.....
2. Grate surface, wide.....long.....area.....
4. Water heating surface.....
5. Superheating surface.....

6. Ratio of water heating surface to grate surface.....
 NOTE.—Items correspond to A. S. M. E. Standard Report of Boiler Trials.
 Results of the Trial of (No. and type).....

- Boilers at
 To Determine
 1. Date of trial
 2. Duration of trial

Average Pressures.

7. Steam pressure in boiler by gauge.....
 8. Absolute steam pressure
 9. Atmospheric pressure per barometer
 10. Force of draught in inches of water.....

Average Temperatures, Fahr.

11. Temperature of external air
 12. Temperature of fire room.....
 13. Temperature of steam
 14. Temperature of escaping gases
 15. Temperature of feed water

Fuel.

16. Total amount coal consumed (includes wood \times 0.4).....
 17. Moisture in coal
 18. Dry coal consumed
 19. Total refuse dry.....pounds,==.....
 20. Total combustible (item 18 less item 19).....
 21. Dry coal consumed per hour.....
 22. Combustible consumed per hour

Results of Calorimetric Tests.

23. Quality of steam (dry steam taken as unity).....
 24. Percentage of moisture in steam
 25. Number of degrees superheated

Water.

26. Total weight of water pumped into boiler and apparently evaporated.....
 27. Water actually evaporated corrected for quality of steam.....
 28. Equivalent water evaporated into dry steam from and at 212° F.....
 29. Equivalent total heat derived from fuel in British thermal units.....
 30. Equivalent water evaporated into dry steam from and at 212° F. per hour.....

Economic Evaporation.

31. Water actually evap., per pound of dry coal from actual pressure and temp.
 32. Equivalent water evaporated per pound of dry coal from and at 212° F.....
 33. Equivalent water evaporated per pound of combustible from and at 212° F.....

Commercial Evaporation.

34. Equivalent water evaporated per pound of dry coal with one-sixth refuse at 70 pounds gauge pressure from temperature of 100° F. (==item 33 \times 0.7249).....

Special.

35. Dry coal actually burned per sq. ft. of grate surface per hour.....
 36. Water evap. from and at 212° F. per sq. ft. of heating surface per hour.....

Commercial Horse Power.

42. On a basis of 30 lbs. water per hour evaporated from a temp. of 100° F. into steam of 70 pounds gauge (==34½ lbs. from and at 212° F.....
 44. Horse-power, Builders rating at.....square feet per H. P.....
 45. Per cent developed above or below rating.....
 NOTE.—Items correspond to A. S. M. E. Standard Report of Boiler Trials.

Very much less elaborate and yet quite instructive, in a comparative way, are the tests conducted by Mr. Edgerton, superintendent of the electric light and water works, Lansing, given below. In these tests a 12 hour run was made of each coal, and an attempt was made to leave the grates in the same condition as they

were found.* The amount of feed water was measured and the feed water kept at a constant temperature of 110°F. The boiler pressure is nearly constant, about 95 pounds to the square inch, and the coal and ashes weighed as shown. Of course there are many chances for inaccuracy. The boiler pressure was not absolutely constant; the variations of atmospheric pressure and the temperature of escaping gases and the dryness of the steam was not noted nor the coal which preceded on the grate, and this might make quite a difference. Most of the above factors, however, would make no material difference in comparative tests. And if we reduce for some of them the water actually evaporated to units of evaporation, i. e., that which would be evaporated from and at 212°F. we find somewhere near the following values:

	U. E. 1st Series.	U. E. 2nd Series.	U. E. 3rd Series.
Average of Hocking Valley coals.....	7.38	8.32	.....
Saginaw.....	7.23	.....	7.32
St. Charles.....	.....	8.16	7.41
Corunna.....	6.49	.....	.....
Williamston.....	{ 6.51 6.94	.....	.....
Bay City (Upper Verne).....	.....	.....	7.56
Bay City (Lower Verne).....	.....	.....	6.75

While the figures of Mr. Edgerton for the heating value of the Saginaw and Hocking Valley coals are much less than those given by Fisher, the relative values agree almost to a per cent. ($8.32 \div 8.26 = 1.01$ and $7.38 \div 7.23 = 1.02$.)

The first set of tests were in 1898. Another set of tests preliminary to awarding the contract in 1899 were made up to June 11, 1899. In this two of the St. Charles coals were represented, the J. H. Somers Coal Company and the Michigan Coal Company. The average result (7.05 pounds actually evaporated=8.15 pounds from and at 212°F.), is just a little less than that of the two Hocking Valley coals ($7.197 = 8.32$ pounds from and at 212°F.), but practically identical with that found for the Saginaw Coal Company by Mr. Fisher.

In a third series from June, 1900, to February, 1901, the best result was about as before and the Somers Coal Company gave about the same result with the Saginaw on the first test, and in

*This is known as the "Alternate method" and seems to be growing in favor compared with the old "Standard method" of starting a new fire for each test.

the same general proportion with other coals as No. 3 and No. 4 of the second series. The coal from the Michigan Coal and Mining Company is from the upper seam and not that analyzed as A10, which does not represent what they ship. This latter was first worked and was analyzed by H. J. Williams. The sample tested at Lansing is probably better represented by Analysis J3.

It is not safe closely to compare the series, as there is probably some difference in the plant which makes one set not comparable with the other. Though the results on the Pocahontas ($9.312 \div 9.229$) and Wellston ($7.622 \div 7.596$) check quite closely, the Hocking Valley coals ran much better the second year.

LANSING WATER-WORKS TEST—FIRST SERIES.

	A.	B.	C.	D.	E.	F.	G.	H.
1.	Cedar Grove.....	Steam lump	8471	804	62581	7.387	82.45	6080
2.	Goshen Hill.....	Run of mine	10162	995	71433	7.080	2.25	6248
3.	Black Diamond.....	" " "	11105	1293	70875	6.881	2.25	5647
4.	Massillon.....	" " "	10407	808	72547	6.971	2.33	5932
5.	Hocking Lump.....	" " "	11163	949	74400	6.634	2.35	5646
6.	New River.....	" " "	18765	524	68471	7.852	3.20	4907
7.	Hocking Valley*.....	" " "	10705	808	71618	6.689	2.31	5791
8.	Cedar Grove.....	" " "	10000	1048	65614	6.561	2.35	5583
9.	Hocking Valley*.....	Pea	12845	1558	75332	5.864	1.94	6046
10.	Mingo.....	Run of mine	9669	682	71486	7.368	2.80	5281
11.	Jackson Hill*.....	" " "	10897	513	71185	6.846	2.50	5477
12.	Riverside*.....	" " "	9062	491	74280	8.196	2.60	6304
13.	Hocking Valley*.....	" " "	11645	1021	74899	6.432	2.34	5497
14.	Saginaw.....	" " "	10754	895	67471	6.374	2.20	5703
15.	Corunna.....	" " "	15551	1440	59520	5.633	2.25	5006
16.	South Side.....	" " "	7896	565	63076	7.988	2.50	6390
17.	Wellston Shaft.....	" " "	8405	120	64066	7.622	2.25	6775
18.	Pocahontas*.....	" " "	7089	235	65428	9.229	3.00	6153
19.	Not known.....	" " "	10073	1097	65862	6.538	2.09	6317
20.	Williamston.....	" " "	11178 10891	440	62335 62015	5.659 6.021	2.40	

A. Name of coal.

B. Grade of coal.

C. Pounds of coal burned during the test.

D. Pounds of ashes.

E. Pounds of water evaporated during the test; feed water temperature,

110° F.=61.89 lbs. per cubic foot.

F. Pounds of water evaporated per pounds of coal.

G. Price of coal delivered in bins.

H. Pounds of water evaporated for \$1.00. Michigan coals are italicized.

1. Bidder, E. J. Corbett. No clinkers; light brown smoke.
2. " Pittsburgh & Wheeling Co. Light clinkers; smoke medium.
3. " Black Diamond Co. Clinkers bad; heavy, dark smoke.
4. " Pittsburgh & Wheeling Co. Light clinkers; smoke medium.
5. " O. W. Shipman. No clinkers; light smoke.
6. " John Dalley. No clinkers; light brown smoke.
7. " " No clinkers; smoke medium. Compare Willcox's test.
8. " E. J. Corbett. Clinkers and smoke medium.
9. " Ohio Central Fuel Co. Clinkers and smoke heavy.
10. " E. J. Corbett. No clinkers; very little smoke.
11. " John Dalley. No clinkers; heavy smoke. Compare Willcox's tests.
12. " O. W. Shipman. No clinkers; very little smoke.
13. " Ohio Central Fuel Co. Clinkers medium; smoke heavy.
14. " Saginaw Coal Co. Clinkers and smoke medium. See other tests and analyses.
15. " Corunna Coal Co. Clinkers and smoke bad; steam hard. See other tests and analyses.
16. " V. R. Canfield. No clinkers; smoke medium.
17. " Milton Coal Co. No clinkers; smoke medium.
18. " V. R. Canfield. No clinkers; very little smoke. See 2nd series.
19. " Wells & Clear. No clinkers; smoke heavy.

LANSING WATER-WORKS TEST—SECOND SERIES.

	Grades of Coal.	Lbs. of Coal burned during the test.	Lbs. of Ashes.	Per cent ashes.	Lbs. of water evaporated during the test. Temperature of feed water, 110 deg. 62 lbs. = 1 cub. ft.	Lbs. of water evaporated per lb. of Coal
	B.	C.	D.		E.	F.
1.	Run of mine....	11789	1142	11.2	74648	6.332
2.	Run of mine....	8929	892	10.0	83142	9.312
3.	Steam lump....	11558	869	7.8	78618	6.902
4.	Steam lump....	12150	1118	11.8	98559	7.311
5.	Run of mine....	11500	1545	13.4	81084	7.046
6.	Run of mine....	10335	1092	10.6	79298	7.672
7.	Three-quarter lump.....	10532	945	9.0	78132	7.432
8.	Run of mine....	10305	500	4.85	78908	7.586
9.	Steam lump....	10110	905	9.0	70494	6.972
10.	Run of mine....	9825	885	9.0	75392	7.672
11.	Run of mine....	9240	740	7.9	69750	7.470
12.	Run of mine....	8008	670	7.8	69006	8.019

1. Montana Coal & Coke Co. Clinkers; not satisfactory to burn.
2. Castner, Curran & Bullitt, Pocahontas. No smoke or clinkers.
3. Michigan Coal Co., St. Charles, Black Pearl. Very light clinkers; heavy smoke. See tests, p. —
4. J. H. Somers Coal Co., St. Charles. Light clinkers; heavy smoke. See tests, p. —
5. W. H. Vance & Co., Kelley's Creek. No clinkers; heavy smoke.
6. M. A. Hanna & Co., Youghiogheny. No clinkers; smoke medium.
7. The Pittsburg Coal Co., Hocking. No clinkers; good burning coal.
8. The Milton Coal Co., Wellston shaft. Light clinkers; smoke medium.
9. Lowery Coal Co., Hocking, Congo. Clinkers and smoke badly.
10. Lowery Coal Co., Boomer, W. Va. No clinkers; light smoke.
11. The O. W. Shipman Co., Peerless, Cedar Grove. Very light clinkers; smoke medium.
12. W. H. Vance & Co., Massillon. No clinkers; light smoke.

LANSING WATER-WORKS—THIRD SERIES.—1900-1901.

	Date of Test. 1900.	Coal burned during Test.	Ash.	Per cent of ash.	Lbs. of water at 62 lbs. per 1 cubic foot.	Water evaporated with 1 lb. of coal.	Water evaporated for \$1.00
1.	June 8.....	10124	1041	10	59290	5.756	4343
2.	June 9.....	8886	730	8.2	66410	7.353	5656
3.	June 12.....	9640	1105	11	58590	6.077	4901
4.	June 13.....	9512	594	6.2	63116	6.635	4625
5.	June 14.....	8520	593	6.9	57350	6.781	5220
6.	June 16.....	10110	895	8.8	64490	6.877	5081
7.	June 21.....	9770	785	8	62992	6.447	5137
8.	June 22.....	9350	595	6.4	59210	6.332	5389
9.	Nov. 11.....	14626	1255	8.6	95604	6.536	5335
	1901.						
10.	Jan. 4.....	13038	1510	8.6	101962	7.880	6123
11.	Feb. 8.....	15916	3180	19.9	93310	6.846	5314
12.	Jan. 20.....	14890	1835	8.1	108168	6.923	5542
13.	Jan. 10.....	12970	1490	11.5	101122	7.796	5846

1. Sandy Creek.
2. Boomer R. M.
3. New Pittsburg R. M.
4. Milton Coal R. M.
5. Pittsburg and Wheeling.
6. Somers' Coal Co., St. Charles.
7. Somers' Coal Co., from different shaft, St. Charles.
8. Pere Marquette Steam Lump (No. 2 Shaft).
9. Michigan Coal and Mining Co. Steam Lump (upper seam).
10. Pittsburg Coal Co.
11. Silver Mather Co., Bay City.
12. Pittsburg Coal Co. No. 8.
13. Pittsburg Coal Co. ¾ coal.

The object of the foregoing section is to show:

First, what the heating power of our Michigan coals is likely to be.

Second, the importance and elaborate character of a thorough boiler test which will show the efficiency not only of the coal, but of the boiler plant,—such a test should be made by a trained mechanical engineer.

Third, the importance in dollars and cents and comparatively simple character of a test which will show the relative efficiency of different coals with same plant.

§ 11. Heating power by calorimeter.

Slosson and Colburn have described and illustrated Mahler's Calorimeter quite fully in the Wyoming bulletin, previously cited, which may be obtained gratis on application. It has been improved by H. J. Williams, in many important details ensuring greater accuracy, yet without modifying the general principle. One of his is in use at Johns Hopkins University and one set of analyses, Nos. A1 to A11, were made on a similar instrument. He has also made one for the United States in testing explosives.

The Mahler Calorimeter was also used by Lord and Haas, and in the test with Pray's Analyses (I3 and I4) at Cornell University.

The Mahler Calorimeter, even unimproved, is by far the most accurate method of testing the heating capacity of the coal, but it is also the most expensive. The Michigan Agricultural College have recently bought a Parr Calorimeter which we illustrate below (Figures 7 and 8), which is quite effective and much less expensive, a description of which will serve to explain the general method of making tests with other calorimeters. The method of making a test with it is as follows:

One gram of coal is weighed out, having been first pulverized so as to pass through a 100 mesh sieve, and dried at 105° to 110°C. (220°-230°F.). This is put into the body of a steel cartridge, A of Fig. 7, D of Fig. 8. To it is added 16 to 18 grams of sodium peroxide (Na_2O_2). The stem of the cartridge, C of Fig. 7, is screwed on. The whole is shaken and the little turbine fans or vanes shown in Fig. 8 attached by spring clips to the outside. The whole cartridge is then balanced on a cone inside a can (A of Fig. 8) containing two litres of water, 3 to 4° colder than the room. In this can a thermometer T is placed. On the top of the cartridge stem which pro-

jects from the indurated fibre insulation (B C), which surrounds the can, a pulley wheel slips, by which the cartridge may be revolved 50 to 100 revolutions per minute, with any light motor.

The stirrer is set in motion by a cord around the pulley P, which

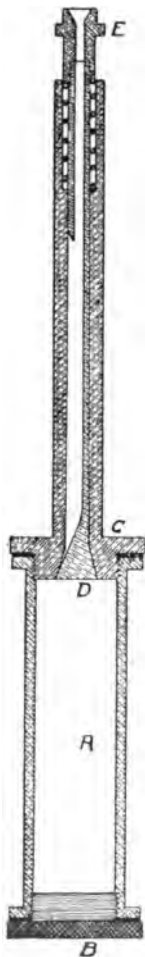


Fig. 7. Cross-section of cartridge for Parr Calorimeter.—See description in text.

runs to any light motor (Plate III) that will turn the cartridge some 50 to 100 revolutions a minute, and a water current is started down past the cartridge through E and up past the bulb of the thermometer T. After a short time the temperature registered by the

thermometer remains so uniform that for a few minutes no change can be noticed, so perfect is the insulation afforded by the indurated fibre pails, B and C and the double lid with the air space between. Then down the stem E a piece of red hot copper wire one half inch long, is dropped. By pressing the top E of Fig. 7, which

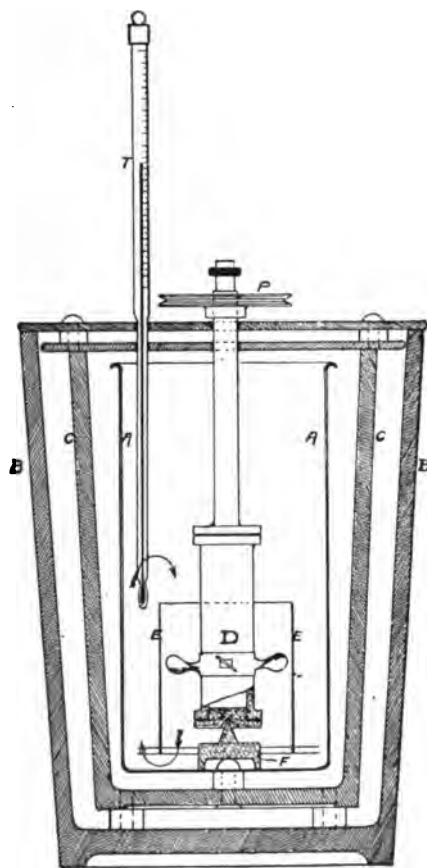


Fig. 8. Cross-section of Parr Calorimeter.—See description in text.

rests on a coiled spring the valve D is lowered so as to allow the wire to enter the chamber A, and start the combustion of the coal at the expense of the oxygen of the sodium peroxide. Heat is evolved and the mercury of the thermometer rises. In four or five minutes the highest point is reached, and the difference between the temperature before firing and after is, after subtracting

0.15°C. for the heat introduced by a piece of No. 12 copper wire one half inch long, in a fixed ratio to the heat in B. T. U. by burning a pound of coal. What this ratio is may ordinarily be best determined by a test on some standard substance, as there is some heat liberated by combination of the CO_2 and H_2O with the sodium oxide. For this purpose sugar charcoal or some other coal whose heating power has already been determined, may be used.

The factor given by the manufacturers is 3,100.

The novel idea embodied in the Parr Calorimeter is the introduction into the combustion chamber and intimate mixture with the coal of a chemical, Na_2O_2 , which not only ensures complete combustion, but absorbs the gaseous products as fast as they are formed, so that enormous strength is not required to prevent their escaping, carrying heat with them. The test becomes rapid and inexpensive.

Now in the bomb calorimeter which is after all the standard, though much more expensive and difficult to manage, the general plan of operation is the same. But the coal is burned in an atmosphere of pure oxygen under pressure, and ignited by electricity. The gases of combustion are not allowed to escape, carrying the heat with them. In consequence the cartridge must be able to withstand an enormous bursting pressure. It is made spherical like a bomb. It has the advantage, however, that the question of the heat of absorption of the gases by the chemicals does not enter and that if need be, a fuel containing moisture can be accurately tested.

Another rather simple form of calorimeter, the Barrus, is figured in the report of the committee of the Mechanical Engineers on Standard Boiler Tests.*

Another modern form of calorimeter is the Carpenter Calorimeter. This was also used in Pray's analysis and by G. B. Willcox for his tests at the University of Michigan and is described in the proceedings of the American Society of Mechanical Engineers.†

The Thompson and other older forms of calorimeter will be found described in most text-books and are still used, but are much less accurate.

*Transactions 1899, No. 827 so many times referred to, also 1893, p. 816.
†Vol. XVI (June, 1895), No. 653.



THE PARR STANDARD CALORIMETER READY FOR IGNITION.

1

2

The **determinations** of the improved bomb calorimeter are the most **accurate** possible and are the standards by which every other **test** of heating power should be judged. Certain cautions must **be** given, however. As we have said it is not easy to get **identical** samples twice, and samples change slightly in keeping, the **more** finely they are ground.

Moreover, in practical work we shall never be able to reach the **perfection** of heat saving reached by the calorimeter. The degree to **which** we do this may be taken as measure of the goodness of the **boiler** arrangements, and as we have seen unless one is getting **nearly 60%** of the theoretical capacity, there is room probably for **improvement** in his boiler practice. Inasmuch as the calorimeter **tests** used to be expensive to make (\$25) and required the use of **an** expensive apparatus not readily accessible, other methods to obtain the theoretical heating power have been widely used.

The following are the results of a series of tests for which we are indebted to G. B. Willcox, at the University of Michigan, with the Carpenter Calorimeter, published in part in the Michigan Miner, March 1.

The agreement with Williams' results is fair for Pocahontas coal, and for the St. Charles Black Pearl, compared with the St. Charles J. H. Somers No. 1. He gets considerably more out of the Pere Marquette and Saginaw than would be expected, unless they had lost quite a little moisture.

The object of introducing the series 12 to 23 is to show the variation of heating power with per cent of ash. Compare the Rifle River and Alpena analyses G4, 5, 7 and 8.* We see from the tests of Mr. Willcox that the heating power decreases in more than the ratio of the ash. Most of the material is from black shales or bone coal. No. 23 is, however, a genuine coal, perhaps from the Lower Verne.

*Also D11, I11, J5 and 6, pp. 113 to 118.

TABLE—CALORIMETER TESTS OF G. B. WILLCOX.

No.		B. T. U.	Per cent Ash.
1.	Riverside.....	15,104	5.1
2.	Pocahontas.....	14,579	4.0
3.	Jackson Hill.....	14,196	7.45
4.	Jackson Hill, Big Drift.....	13,987	5.55
5.	Montana Lump.....	14,325	5.3
6.	Bellmore, W. Va.....	13,850	5.4
7.	New River.....	13,763	7.25
8.	Massillon.....	12,105	8.1
9.	Hooking Drift.....	11,935	9.33
10.	Jackson, Mich.....	10,070	9.1
11.	Jackson Hill.....	14,500	3.9
12.		8,884	37.8
13.		8,663	40.8
14.		8,618	42.8
15.		8,374	42.8
16.		7,967	42.7
17.	Tests of exploratory drillings near West Bay City.....	4,917	47.0
18.		5,123	47.7
19.		4,666	49.6
20.		9,125	23.
21.		9,633	23.
22.		6,866	36.
23.		12,600	9.6
24.	Saginaw Coal Co.....	13,000	3.25
25.	Pere Marquette.....	13,687	2.25
26.	Black Pearl, St. Charles.....	13,167	1.00

RIVERSIDE COAL. No. 1 of Table.

Mine located at Riverside, W. Va. Sample obtained from the University of Michigan laboratory. Tested by Carpenter Calorimeter. Date of test, May, '97. Observer, I. C. Woodward, '97 thesis. Tested at U. of M. laboratory. Preparation of sample: Has been stored in a dry place for several years. Sample obtained by a system of quartering.

Quantitative analysis made by A. R. Miller, B. S. (Chem.) '97:

Per cent of water	1.53%
Per cent of volatile matter	28.5%
Per cent of fixed carbon (plus fixed sulphur).....	55.07%
Per cent of ash	4.91%
Per cent of total sulphur	0.564%
B. T. U. in volatile matter	7,129
B. T. U. in fixed carbon	7,975
	<u>15,104</u>

POCAHONTAS COAL. No. 2 of Table.

Mine located in Wise County, W. Va. Sample obtained from the University of Michigan laboratory. Tested by Carpenter Calorimeter. Date of test, May, 1897. Observer, I. C. Woodward, '97 thesis. Tested at the U. of M. laboratory. Preparation of sample: Had been stored in a dry place for several years. Sample was obtained by a system of quartering.

Quantitative analysis made by A. R. Miller (B. S. Chem. '97):

Per cent of water	0.50%
Per cent of volatile matter	20.43%
Per cent of fixed carbon (plus fixed sulphur).....	74.07%
Per cent of ash	4.98%
Per cent of total sulphur	0.865%
B. T. U. in volatile matter	3,849
B. T. U. in fixed carbon	10,730
	<u>14,579</u>

See also test reported by R. C. Carpenter, Vol. XVI A. S. M. E.

JACKSON HILL COAL. No. 3 of Table.

Mine located at Jackson Hill, Ind. Sample obtained from the University of Michigan laboratory. Tested by Carpenter Calorimeter. Date of test, May, 1897. Observer, I. C. Woodward, '97 thesis. Tested at U. of M. laboratory. Preparation of sample: Had been stored in a dry place for several years. Sample was obtained by a system of quartering.

JACKSON BIG DRIFT. No. 4 of Table.

Mine located at same point. Sample obtained from the University of Michigan laboratory. Tested by Carpenter Calorimeter. Date of test, May, 1897. Observer, I. C. Woodward, '97 thesis. Tested at U. of M. laboratory.
Preparation of sample: Had been stored in a dry place for several years. Sample was obtained by a system of quartering.

MONTANA LUMP COAL. No. 5 of Table.

Mine located at Fairmont, W. Va. Sample obtained from the University of Michigan laboratory. Tested by Carpenter Calorimeter. Date of test, May, 1897. Observer, I. C. Woodward, '97 thesis. Tested at U. of M. laboratory.
Preparation of sample: Had been stored in a dry place for several years. Sample was obtained by a system of quartering.

BELLMORE COAL. No. 6 of Table.

Mine located at Bellmore, W. Va. Sample obtained from the University of Michigan laboratory. Tested by Carpenter Calorimeter. Date of test, May, 1897. Observer, I. C. Woodward, '97 thesis. Tested at U. of M. laboratory.
Preparation of sample: Had been stored in a dry place for several years. Obtained by a system of quartering.
Quantitative analysis by A. R. Miller:

Per cent of water	1.50%
Per cent of volatile matter	35.53%
Per cent of fixed carbon (plus fixed sulphur).....	58.2%
Per cent of ash	4.98%
Per cent of total sulphur .....	.76%
B. T. U. in volatile matter	5,440
B. T. U. in fixed carbon	8,410
	<hr/> 13,850

NEW RIVER COAL. No. 7 of Table.

Mine located at Fayette Co., W. Va. (Loup Creek). Sample obtained from the University of Michigan laboratory. Tested by Carpenter Calorimeter. Date of test, May, 1897. Observer, I. C. Woodward, '97 thesis. Tested at U. of M. laboratory.
Preparation of sample: Had been stored in a dry place for several years. Sample was obtained by a system of quartering.

MASSILLON COAL. No. 8 of Table.

Mine located at Massillon, Ohio. Sample obtained from the University of Michigan laboratory. Tested by Carpenter Calorimeter. Date of test, May, 1897. Observer, I. C. Woodward, '97 thesis. Tested at U. of M. laboratory.
Preparation of sample: Had been stored in a dry place for several years. Sample obtained by a system of quartering.
Quantitative analysis by A. R. Miller (B. S. Chem. '97):

Per cent of water.....	1.7%
Per cent of volatile matter	40.48%
Per cent of fixed carbon (plus fixed sulphur).....	51.2%
Per cent of ash	6.55%
Per cent of total sulphur	2.90%
B. T. U. in volatile matter	4,710
B. T. U. in fixed carbon	7,395
	<hr/> 12,105

HOCKING DRIFT COAL. No. 9 of Table.

Sample obtained from the University of Michigan laboratory. Tested by Carpenter Calorimeter. Date of test, May, 1897. Observer, I. C. Woodward, '97 thesis. Tested at the U. of M. laboratory.
Preparation of sample: Had been stored in a dry place for three months. Sample was obtained by a system of quartering.

JACKSON. MICHIGAN. COAL. No. 10 of Table.

Mine located four miles from Jackson, Michigan. Sample obtained from the University of Michigan laboratory. Tested by Carpenter Calorimeter. Date of test, May, 1897. Observer, I. C. Woodward, '97 thesis. Tested at the U. of M. laboratory.
Preparation of sample: Had been stored in a dry place about three months. Sample obtained by a system of quartering.

JACKSON HILL COAL. No. 11 of Table.

Mine located at Jackson Hill, Ind. Sample obtained from University of Michigan laboratory. Tested by Carpenter Calorimeter. Date of test, November 1,

1898. Observer, G. B. Willcox. Tested at U. of M. laboratory. Temperature of room 75° F.

NOTE.—This coal is very clear and free burning; no smoke from discharge opening from calorimeter.

Nos. 12 to 23 are of drillings.

SAGINAW COAL COMPANY. No. 24 of Table.

May 20, 1899. Sample submitted by Robert M. Randall, manager. Sample consisted of about ten pounds of medium and small lumps packed in tight wooden box. Received by express.

General appearance: Burns clear and bright. Steady pressure in the combustion chamber. No smoke emitted. Combustion ceases suddenly without glow and leaves a light feathery white ash.

PERE MARQUETTE MINE. No. 25.

May 20, 1899. Sample submitted by Robert M. Randall, manager Saginaw Coal Company. Sample consisted of about ten pounds of medium and small pieces packed in a tight wooden box. Received by express.

General appearance: Burns clear and bright. Steady pressure in combustion chamber. No smoke emitted. Combustion ceases suddenly without glow and leaves a light colored ash without perceptible traces of fusible matter.

BLACK PEARL MINE. No. 26.

May 22, 1899. Owned by Northern Coal and Transportation Company, St. Charles, Michigan. Sample consists of a single lump picked up at the mine. No attempt was made to get a representative sample by quartering, but the lump selected was in general appearance an average sample.

General appearance: Burns clear and bright in the crucible. No smoke emitted from the combustion chamber. At the close of the test the glow is suddenly extinguished, and the ash shows no appreciable tendency to fuse. Ash is light and feathery.

The low per cent of ash in this select lump illustrates what we have said about the ash being in the finer stuff and slack.

§ 13. Heating power by reducing power. Berthier's method.

This method is an old one introduced by Berthier in 1833 and used somewhat by Prof. F. S. Kedzie. Recently Kerr, as above cited, has tried to improve upon it, but has made an error in theory which we shall endeavor to correct and at the same time derive formulæ easily simplified, yet sufficiently approximate for Michigan practice. Berthier's process is as follows:

Let the coal to be tested be intimately mixed with litharge PbO in the proportion of 20 to 40 (Berthier), or 50 (Kerr), of the litharge to one of coal and then placed in a crucible covered with a layer of PbO , and heated gradually. The coal will burn largely at the expense of the oxygen. Berthier assumed that all the combustible was carbon, but in reality we have, as Kerr remarks, hydrogen also, which gives out much more heat in proportion to the oxygen consumed. To see what the relation will be let:

x —amount of lead reduced by the weight of hydrogen h , changing to H_2O

y —amount of lead reduced by the weight of carbon c , changing to CO_2

z —amount of lead reduced by the weight of sulphur s , changing to SO_2

w=amount of lead reduced by the weight of iron f, changing to Fe_2O_3

$$x = \frac{206.9}{16} \cdot \frac{16}{2.02} h \text{ or } x = 102.42 h$$

$$y = \frac{206.9}{16} \cdot \frac{32}{12} c \therefore y = 34.48 c$$

$$z = \frac{206.9}{16} \cdot \frac{32}{32.06} s \therefore z = 12.93 s$$

$$w = \frac{206.9}{16} \cdot \frac{48}{112} f \therefore w = 5.54 f$$

$$z + w = 12.93 s + 554 \left(\frac{1}{8}\right) s = 17.78 s.$$

—if we assume, as Hilton's work shows that we may, that the sulphur and iron are combined in pyrite, so that we have $f=\frac{1}{8}s$. Assuming also, that heat of oxidation of the pyrite is 40 B. T. U. per unit of sulphur, of the carbon 14,600 B. T. U., and of the hydrogen 62,000 B. T. U. we shall have if P be the heating power per unit (gram) of fuel,

$$\begin{aligned} P &= 14,600 c + 62,000 h + 4,000 s \\ &= \frac{14,600 y}{34.48} + \frac{62,000 x}{102.42} + \frac{4,000(z+w)}{17.78} \\ &= 423.4 y + 605 x + 225(z+w) \\ &= 423.4 (x + y + z) + 181.6 x - 198.5 (z + w) \\ &= 423.4 (x + y + z + w) + 18,638 h - 3,530 s. \end{aligned}$$

Now $(x+y+z+w)$, the total amount of lead reduced in grams is determined by experiment and the result obtained by neglecting the other two terms is Berthier's formula for the heating value. But omission of these two terms introduces considerable error.

Kerr also neglects the term containing s or $z+w$ which introduces no very large error. Since, for instance, in our Michigan coals the sulphur of the pyrite runs from 0.82 to 6.67% the error made by neglecting the term containing s will average 113 B. T. U. and will in no case exceed 256 B. T. U. The term containing h is more important, and may amount to over 1000 B. T. U.

Kerr attempts to allow for this term $18,638 h$ by adding $\frac{18,638 h}{34.48}$ to the coefficient 423.4, and assuming a value for h according to the class of the coal, .02 for anthracite, .05 for bituminous coal. Thus, for our coals $P = 450 (x+y+z+w = \text{total lead reduced})$, by Kerr's formula. Of course if an ultimate analysis has been made we could determine h more exactly, but in that case the heating value can be as well computed by Dulong's formula.

But this correction of Kerr's will obviously be approximately correct, only when $x+y+z+w$, the total amount of lead produced per unit of fuel is nearly 34.48, that is to say when the fuel is pure carbon or the amount of ash present balances the amount of hydrogen so that the reduction of lead is the same as though it were all pure carbon. A glance at his table shows that this is not generally the case. Usually it will fall short and in such cases his estimates of the heating power are short,* unless the hydrogen is overestimated.†

For our Michigan coals we see that the hydrogen‡ averages almost exactly .04 so that we may rewrite the formula.

$$P = 423.4 (\times \text{total lead produced}) + 623 + 18,638 (h - .04) - 3,530 (s - .0321).$$

The last term we can compute if the coal has been analyzed for sulphur. It may run 100 units more or less. The hydrogen term ought not to vary more than a couple of hundred units. Comparisons seem to indicate that even with this formula the lead method gives too low results. There are errors in other ways. For instance a certain amount of oxygen will be derived from interstitial air. If we may judge from Kerr's tests on sugar charcoal it may correspond to 260 B. T. U. The PbO is liable to contain some Pb₂O₃ and the iron instead of being oxidized may be alloyed with the lead. On the whole I think that the lead results even with this formula must be taken as minimum.

§ 14. Heating power computed from ultimate analysis.

The heating power of a coal is often stated in B. T. U. not per pound of coal, but per pound of dry coal or per pound of combustible, i. e., coal free from ash and moisture, and occasionally (so by Lord and Haas) per pound of fuel, minus ash, moisture and sulphur. The more the above constituents are eliminated the more nearly constant the heating power is found to be. Now, if we have an ultimate analysis of the coal there is a formula known as Dulong's from which we can compute the heating power nearly as accu-

*For instance, in analysis No. 80 of his table I, if we assume 5% of hydrogen, a better estimate of the heating power would be about 12,900 instead of 11,915. It is easy to see that in his table II comparing oxygen and litharge methods, in treating pure sugar carbon or anthracite, his results will be in this respect nearly correct, while for bituminous slack, if my criticism is just, they may be, as indeed they appear to be about a thousand B. T. U. too low.

†For instance coals I9 and I10 which gave, with the Parr Calorimeter, 12,508 respectively, 13,438 B. T. U., reduced 27,397, respectively, 27.36 grams of lead per gram of coal used, i. e., 12,320 to 12,300 by Kerr's formula or by the one we have suggested, 12,223 B. T. U. the overestimate of the percentage of hydrogen compensating for the error in the formula.

‡Or rather the hydrogen effective in reduction ($H - \frac{1}{8} O$).

rately as it is determined by a calorimeter. It is written in two or three different forms which are substantially the same. Lord and Haas use it in this shape:

Heating power in calories = $8080c + 34,462(h - \frac{1}{8}o) + 2250s$.

c, h, o and s being the amounts of carbon, hydrogen, oxygen and sulphur in one unit of coal. For 8080 some use 8140; for o, $o + n - 1$. If the C is burned to CO, not CO₂, 34,462 must be replaced by 29,000. Sometimes 600 or 1000w (where w = moisture) is subtracted, but this must not be done in comparing with a calorimeter of the bomb pattern, as the hot gases are not allowed to escape.

Heating power = $14,544c + 62,031.6 + (h - \frac{1}{8}o) + 4,050s$, is the equivalent formula in B. T. U., but the boiler committee of the A. S. M. E. suggest the following form:

Heating power in B. T. U. = $146C + 620 \left[H - \frac{O}{8} \right] + 40 S$.

Kent in Mineral Industry, 1899, for 146c writes 146.5c.

In this formula the C, H, O, and S, are 100 times greater than c, h, o and s, being percentages instead of fractions of unity.

We have calculated and find that for Williams' analyses A1 to A17, at any rate, no closer agreement with the result of calorimeter experiment is made by attributing any effect to the moisture. As regards the use of $\frac{1}{8}O$ instead of $\frac{1}{8}(O+N-1)$, $\frac{1}{8}(N-1)$ is respectively .05, .04, .05, .06, .03, .02, so that its effect is trifling, not exceeding 40 B. T. U., which is much less than the errors due to analysis and sampling.

Using the A. S. M. E. formula therefore we have (computing by slide rule) the following table:

TABLE.—COMPARISON OF WILLIAMS' CALORIMETRIC TESTS AND DULONG'S FORMULA.

Analysis Number.	Heating units by Calorimeter.	Computed by Formula.	Differences.		(H — $\frac{1}{8}$ O)
A. 1.	12,726	12,688	.....	— 38	3.64
2.	12,868	12,876	+ 8	.....	3.84
3.	12,836	12,506	.....	— 330	3.32
4.	13,016	13,089	+ 23	.....	3.81
5.	13,569	13,755	+ 186	.....	4.72
6.	13,502	13,581	+ 79	.....	4.66
7.	12,359	12,335	.....	— 24	4.24
8.	12,861	12,702	.....	— 159	4.17
9.	12,714	13,087	+ 323	.....	4.62
10.	12,012	11,681	.....	— 331	3.79
11.	12,099	12,035	.....	— 64	3.99
			+ 619	— 946	

The errors in excess and deficiency are almost equally balanced in number, but both in number and size of errors the computed heating powers are a little below those actually found. Thus, it is obvious that substituting 145.44 for 146 or any lower coefficient for C and H or introducing the term $-\frac{1}{8}(N-1)$ would not improve the agreement. Nor would it help to add the oxygen absorbed by the ash when the iron changed to Fe_2O_3 to the oxygen. But to use Kent's value for the coefficient of C, to-wit: 146.5 would make a distinct improvement, for then the errors in excess and in defect would be practically equal.

It would help a little to assume that the iron in uniting with the oxygen gave out more heat than it absorbed in parting from the sulphur. But the discrepancies are not particularly in the S. No. A3, which is one of those most seriously out has but little sulphur, and the ultimate analysis shows nearly $\frac{1}{2}\%$ of hydrogen less than Nos. A1 and A2, while it has more volatile combustible. On the other hand the oxygen set down for A3 is considerably larger than any other analysis. As will be seen below, the results of computation from the proximate analysis check much better with the results of the calorimeter tests.

An error of less than 0.5% in the hydrogen would account for the discrepancy. Lord and Haas state the limit of possible error in an ultimate analysis as 0.5% in carbon and 0.2% in hydrogen.

In No. 9 also, where the greatest error occurs in the other direction the hydrogen is abnormally high and the oxygen low, and computation from the proximate analysis agrees quite well with the observed result. In No. 5, also, are the hydrogen and the computed value high, and in No. 10 the hydrogen low and the computed value low.

Unless these errors are due to errors in the determination of hydrogen, therefore, too much weight is given to the hydrogen.

If we plot the differences between computed and observed heating power referred to hydrogen, we shall find distinct indication that too much weight is given to the hydrogen. But taking the analyses of coals outside the state given for comparison we find no such indications, as we see from the following table:

	H — $\frac{1}{8}$ O	Heating Power by Calorimeter.	Heating Power by Dulong For.		
C.1.....	3.41	12,885	12,630	.....	— 255
C.2.....	— 4.04	13,867	13,565	.....	— 302
C.3.....	— 4.49	14,572	14,514	.....	— 58
C.4.....	— 4.22	14,880	14,748	.....	— 132
C.5.....	3.12	11,674	11,413	.....	— 261
C.6.....	3.71	13,151	13,287	+ 116	.....
C.7.....	— 4.19	13,404	13,326	.....	— 78

So that while we might add an empirical term to the Dulong formula and make the errors of more nearly even size, the improvement would hardly be sufficient ground for changing from the common formula, except Kent's change from 146 to 146.5, which gives a distinct but slight improvement.

§ 15. Heating power computed from proximate analysis.

Let us assume that we have determined volatile combustible v , fixed carbon f , sulphur s , and ash. We will assume as we found in testing the Dulong formula that the moisture and the ash have no effect. The fixed carbon we shall assume has the same effect as the carbon in the Dulong formula (though it really includes about $\frac{1}{2}$ the volatile sulphur), and to begin we shall neglect the fact that this is determined too low when the ash contains much oxidized iron.* The remainder of the carbon is included in the volatile combustible. The table below shows how nearly fixed the proportion of carbon is in the volatile combustible. We subtract fixed carbon of proximate from total carbon of ultimate analyses of Table A and find ratio to volatile combustible:

TABLE—PROPORTION OF C. IN VOLATILE COMBUSTIBLE.

Analyses	A 1	2	3	4	5	6	7	8	9	10	11
C.....	71.11	71.07	71.37	72.88	73.55	72.42	65.87	68.33	68.07	62.29	63.59
Fixed C.....	53.96	53.80	52.58	52.96	45.28	44.64	41.16	45.15	46.06	41.67	42.16
Diff.....	17.16	17.87	18.79	19.92	28.27	27.78	24.71	23.18	22.01	20.62	21.43
Vol. C.....	33.14	33.59	34.74	35.70	46.73	46.59	38.45	39.79	39.59	39.62	40.97
Ratio.....	.518	.530	.540	.567	.605	.593	.642	.582	.556	.520	.528
Average.....	.561	±.04	.....	.....	.....	.....	.....	.....	.....	.....	.....

We see that the average is $.561 \pm .04$

Thus, we may assign $146.5 \times .561 = 82.2 \pm 5.9$ units to each per cent of volatile matter on the score of the carbon contained.

Next let us find the ratio of $(H - \frac{1}{8} O)$ to volatile combustible.

*As shown in table A, the error introduced by the S in the fixed carbon is insignificant.

The following table gives the ratio of $H-\frac{1}{8}(O+N-1)$ to volatile combustible for the first 11 analyses:

Analyses.	A 1	2	3	4	5	6	7	8	9	10	11
H.....	4.74	4.90	4.48	4.81	5.77	5.73	4.90	5.00	5.26	4.62	4.73
$\frac{1}{8}O$	1.10	1.08	1.16	1.00	1.05	1.07	0.66	0.63	.64	.85	.79
$H-\frac{1}{8}O$	3.64	3.84	3.32	3.81	4.72	4.66	4.24	4.17	4.62	3.77	3.90
$N-1$.....	.40	.30	.40	.45	.50	.50	.01	.25	.49	.20	.19
$\frac{1}{8}(N-1)$.....	.05	.04	.05	.06	.06	.06	.10	.03	.06	.03	.02
Vol. matter....	35.9	33.0	32.7	35.75	46.6	46.0	33.45	39.70	39.59	37.4	39.7
Ratio Vol. m't'r	1.088	1.122	.0942	1.051	.0997	.0987	1.101	1.086	1.153	1.008	1.008

The average value of $H-\frac{1}{8}(O+N-1)$ is 4.03 or, including Dr. Koenig's analysis 4.00, of $H-\frac{1}{8}O$ is .04 more. The average value of the volatile matter is 39.00 and the ratio as we easily see is 0.104, just about one tenth of the volatile matter, so that we may also allow for each per cent of volatile matter $620 \times 0.104 = 64.5$ heat units on this account. Consequently we may in average assign $64.5 \times 82.2 = 146.7$ heat units to the volatile matter,—so nearly the same amount as the fixed carbon had that we may count it the same for both, say 146.6.

To the effect of the sulphur is hard to give theoretically even an approximate value. If there is oxygen added to the ash so as to make Fe_2O_3 out of the iron, and just enough iron is present to make FeS_2 then $\frac{3}{8}$ as much oxygen as sulphur is thus added to the ash, so that the chemist may estimate the carbon too low by that much.

We might accordingly allow and add for each per cent of S $\frac{3}{8}$ of 146 or 55 heat units on account of this deficiency in carbon. But on the other hand about half (the amount is not fixed) of the sulphur has been counted in the fixed carbon and allowed a heating value as though it were carbon. Accordingly $\frac{1}{2}$ (146—40) or 53 units should be subtracted on this account. Thus, as we see in Table A, the net result will be almost no change. One might suggest that inasmuch as the sulphur is included in the volatile combustible, in giving it any heating value apart therefrom, we were counting it twice and should deduct accordingly. But that is not true for the ratios to H and C of the volatile combustible were fixed, including the sulphur in the latter, and 146.7 heat units to each per cent of volatile matter is assigned on account of the H and C contained and not the S.

The Dulong formula assigns 40 heat units to the sulphur for its own combustion. It is not certain that the oxidation of the iron above mentioned really occurs completely. Ash is not infrequently magnetic. There may also be compensating loss of combined H from the clay, CO₂ from the calcite, etc. But on the whole we will take as an average formula for derivation of heating power from proximate analysis, if we use Kent's coefficient for the C,

Heating power = $146.6 (f+v) + 40s$.

Plate II, however, was computed for 146 times various values of $(f+v)$. To the heating value in B. T. U. as derived by Plate II from the combustible therefore it will be well to add about 100 B. T. U. for a coal which appears low in sulphur, and 200 for one high in sulphur, in case the sulphur is not exactly determined, to get the best estimate of the heating power.

In the following table the results of computation by this formula are compared with the results of tests with Williams' Calorimeter.

TABLE.—COMPARISON OF COMPUTATION FROM PROXIMATE ANALYSIS WITH CALORIMETER TEST.

	A. 1.	A. 2.	A. 3.	A. 4.	A. 5.	A. 6.	A. 7.	A. 8.	A. 9.	A. 10.	A. 11.
Total Combustible $f + v$	87.00	87.30	87.32	88.66	92.01	91.23	79.61	84.94	86.65	81.27	82.73
146.6 $(f + v)$	12,778	12,822	12,812	12,997	13,487	13,374	11,644	12,452	12,536	11,914	12,128
40 s.....	44	40	40	60	113	123	119	153	229	266	277
B.T.U. computed.	12,822	12,862	12,852	13,057	13,600	13,497	11,763	12,605	12,765	12,180	12,405
B. T. U., Test.....	12,726	12,868	12,836	13,016	13,569	13,502	12,359	12,861	12,714	12,012	12,099
	+ 96	— 6	+ 16	+ 41	+ 31	— 5	— 596	— 256	+ 51	+ 168	+ 306
Ratio of $f : (f + v)$	.618	.616	.602	.597	.492	.489	.518	.532	.538	.510	.519

General average of A. 1 to A. 11 is .516

Average of A. 1 to A. 3 is 0.612 ± 0.010 , probably the Saginaw seam.

Average of A. 5 to A. 6 is 0.490 ± 0.002 , Jackson coal, the Lower Verne.

Average of A. 7, A. 10 and 11, 0.515 ± 0.005 , Lower Bay City, the Lower Verne.

Average of A. 8, A. 9, 0.535 ± 0.003 , both Verne coals together.

We see that the agreement with the calorimeter tests is in general quite as good as that of the Dulong formula, and in but one case is the error greater.

The cases where it does not agree are all coals high in sulphur and ash, yet no higher than others for which it works well. I think that in such cases it is more difficult to get true average samples.

Kent has constructed a diagram* to show how the heating power varies with the proportion of fixed carbon in the combustible $(f+v)$,

*Mineral Industry, 1892 and 1900.

it being greatest when the fixed carbon is 80% of the combustible, i. e., about 158.4 (f+v). It would be according to his formula 146.6 (f+v) when f was 59% of f+v. This is close to the ratio for the first three analyses above from the Saginaw seam, where also the heat of the sulphur does not make much difference. For these analyses, therefore, our formula, which may be considered as an empirical adaptation of Dulong's, is nearly accordant with Kent's. But for most of the remaining analyses, probably from the Verne seams, Kent's formula would give results far too low. However, Kent remarks that his formula does not apply well and gives too low results in the case of certain gas coals where the fixed carbon is less than 58%, such as these Verne coals are.

Lord and Haas proceed a little differently. From f+v they subtract s, i. e., find the combustible free from sulphur, as well as moisture and ash. Subtracting from the heating power of any coal that fairly attributable to the sulphur, and dividing the remainder by the combustible, ash, moisture and sulphur free, we find the heating power of the latter which they call H.

$$H = \frac{P - 40s}{f + v - s}$$

For Hocking Valley (Middle Kittanning) coal they find H=142.75 so that $P=(H=142.75) \times (f+v-s) + 40s$. See last row of table A.

We see, therefore, that their formula is very much of the same type as that we have derived independently from Dulong's formula, connecting the proximate and ultimate analysis of our Michigan coals, except that they have separated the sulphur entirely from the other combustible, which is theoretically correct, but practically inconvenient, and I doubt if there is any compensating increase in accuracy. At any rate no better agreement with the calorimeter tests appears to be obtained, and our formula can be applied more directly to the proximate analysis.

They have not allowed for increase in weight of the ash.

It is also to be remarked that the analyses of Williams upon which our formula is based (Table A) are exceptionally high in moisture and show more than is shown by other analyses of the same coals. Now it is quite likely that Kent's formula was based on compiled analyses in which the moisture was imperfectly separated from the volatile combustible, in which case we should expect that the volatile combustible would appear to have less heating power. For instance, in the gas tests at Pittsburg a sample of

Pere Marquette No. 2 coal (F8) was returned as having but 1.98% of moisture and 43.49% of volatile combustible. It is reasonably certain that the coal is essentially the same as the coals of analyses A1 and A3, and the moisture imperfectly driven off. Clay and pyrite retard the departure of the moisture. Lord and Haas' determinations of moisture were also made at a lower temperature, and their determinations are probably less.

Moreover, in view of the fact that crude petroleum has a heating power of about 10,500 calories or 18,900 B. T. U., it would seem quite likely that the volatile combustible matter, if carefully separated from the moisture, would have as high heating value as the fixed carbon, so that the supposition that it has less is very likely due to imperfect separation of moisture from it.

It is, of course, true that a large part of the difference in percentage of moisture is due to actual difference in the amount contained in the coals. The more finely divided it is the more moisture it seems to lose, the amount depending also upon the humidity of the atmosphere and the temperature and pressure. Prof. F. S. Kedzie finds that practically all the moisture is abstracted over sulphuric acid in vacuo, if the coal is finely powdered.

If we calculate the heating power of the sample analysis No. I1 the result will be 509 units in excess of the calorimeter result. If we apply it to Nos. I3 and I4, and assume one per cent of S, which is probably about right, we shall find the result nearly 1000 B. T. U. more than the calorimeter gave.

The calorimeter results of Nos. I3 and I4 are very low by any formula, or under any supposition, unless the heat carried off by the high percentage of moisture was not counted in. By comparison with analyses A1, I1, I2 and F8 on substantially the same coal we see how much the percentage of moisture varies, in the statements of different chemists.

§ 16. Analyses and samples described.

(A). *Analyses by H. J. Williams.*

All our work has been based upon the eleven analyses made for us by H. J. Williams. It should be said at once that these samples are not put forward to represent the coal as shipped* necessarily, though in most cases they are intended to be a fair sample of the coal as it occurs in the workable seam. They were not intended to replace commercial analyses, but to give some idea of the variety

*In which the sulphurous part may be removed or slate by carelessness enclosed.
12-Pr. II

of quality in Michigan coal, and if possible to serve as a basis by which one could from the proximate infer the ultimate analysis. This we have found that we can do in comparable analyses of the same set, but can in general only do with great caution, for different chemists seem to vary widely in drawing the line between moisture and volatile combustible, in these quite hygroscopic coals. Plate II gives a correlation of the different methods of expressing the heating power of coals, and also shows roughly what heating power may be expected from a given percentage of combustibles, or a given amount of lead reduced, in our Michigan coals, based upon Williams' analyses. Other analyses by other analysts all show less moisture relatively, but the heating power per unit of combustible comes out less, showing in all probability that the moisture was not so thoroughly separated in analysis, even if the coals had lost some moisture before analysis.

Analysis No. A1, from Pere Marquette Shaft No. 1, location, N. W. $\frac{1}{4}$ of section 32, Buena Vista township, T. 12 N., R. 5 E., about 300 paces S. and 700 paces E. of junction of Hess St. and Genesee avenue. The coal at the shaft rises in all directions, but rather rapidly to the east 14 feet or more and ceasing to have sufficient roof. A section of the seam is as follows from top to bottom:

Thin bedded poor coal ("bone coal").....	7 $\frac{3}{4}$ inches.
Slate parting	1 $\frac{1}{4}$ "
Top of coal rather sulphury, not so much so in all places	4 "
Main coal seam from which sample of about 25 lbs. was taken about 50 yards south of the main shaft close to the south entry	32 "

A section of the strata near the shaft would be:

Clay	104	
Sand and gravel	3	107
Till (hardpan)	2	109
Good shale (slate) roof.....	19	128
Coal	3	131
Clay	1	132

The sample was taken by A. C. Lane April 15, 1899, reported June 26, reanalyzed by A. N. Clark (No. E1) about August, 1899, and again partially with iron determination about February, 1900, by C. H. Hilton (No. D1) with accordant results, and again later (reported August, 1900), by Reed and Bradley (H7 & 8). There has apparently been a gradual loss of about 4% moisture.

The Standard Mine (No. A2) is close by, though the coal is not continuous, being separated by a barren area, but the Saginaw

Mine is in the same continuous seam (analyses F3 and I1 to 18), the water draining down into it as it is 12 feet deeper.

Analysis No. A2. From the Standard Mine, Saginaw, in the N. E. $\frac{1}{4}$ of Sec. 6, Bridgeport township, T. 11 N., R. 5 E.

The coal is 147 feet below the surface at the main shaft.

The following is the section as shown by the recent air shaft, which is south of the main shaft (Part I, p. 33):

Sandy clay	80	
Fine grained blue clay	10	100
Impure "fire-clay"	3	103
Shale, dark	8	111
Conglomerate	4	115
Black shale	20	135
Coal, about	4	139
Fire-clay (fern leaves)	6	145

Where taken there is 4 inches of top coal with more ash, and below 44 inches of the main coal seam which was sampled.

Though this mine is not two miles from the Saginaw and Pere Marquette No. 1 shaft, it is separated from them, I am told, by a barren area. At this mine the shales have a fair flora, referred to in the letter of D. White.

According to H. J. Williams' report, June 26, 1899, the coal does not swell up or coke, but cinters together and forms a hard cake; reanalyzed with iron determination February, 1900, by C. H. Hilton (D2).

No. H2, by F. F. Bradley, is from the same mine, but a different sample. The ash agrees closely.

Do not confuse this with the Michigan Standard Coal at Sebewaing. This is apparently the same coal seam as No. 1, and the analyses there cited should be compared.

Analysis No. A3. This is an analysis of about 25 lbs. of coal from the J. H. Somers Coal Co., Shaft No. 1, at St. Charles, Sec. 5, T. 10 N., R. 3 E. J. T. Phillips, superintendent; F. G. Benham, agent. The coal rolls so much that considerable sections are exposed in the fire-clay and roof. The total exposed section being:

	Feet.	Inches.
Blue clay	14	
Hard bed, carbonates of iron		1½
Blue shale	3	
Low grade "Cannel coal"		3
Main seam (as sampled)	2	11

On the south side of the mine is more of the so called cannel, on the north side, none. A section at the shaft is:

Clay	28	
Sand and clay	3	31
Hardpan	9	40
Quicksand	2.5	42.5
Black shale	25	67.5
Gray shale	18.5	84.0
Sandrock	19	103
Shale	0.5	103.5
Coal (the Lower Verne?).....	2	105.5
Fire-clay	6	111.5
Gray shale	8	119.5
Black shale	4	123.5
Fire-clay	4.5	128.0*
Gray shale	23	151.0
Black shale	2.5	153.5
Fire-clay	0.5	154.0*
Black shale	25.5	179.5
Coal (Saginaw Seam)	3.5	182

We notice that beside the coal worked there is another coal at 105 feet which is said to be sometimes $2\frac{1}{2}$ feet thick, more sulphurous and of inferior quality, dipping 4 feet in the 18 feet of the breadth of the shaft.

Taken April 13, returned June 26, 1899. Upon being heated the above coals, A1, A2 and A3, do not swell up and coke but cinder together and form a hard cake. Reanalyzed with iron determination by C. H. Hilton, February, 1900 (D3).

It has also been tested by the Parr Calorimeter (February, 1901) with results of 12,586 to 12,741 B. T. U., or when dried 12,663 B. T. U. The moisture of the sample has diminished to 5.59%.

Analysis No. A4 (B4 & D4) is of a sample from the mine of the Owosso Coal and Mining Co., R. E. Travis, proprietor, taken May 31st, 1899. The present shaft is about 40 rods east and 150 rods north of the old shaft, which I visited in 1895, in the N. W. $\frac{1}{4}$ of the N. W. $\frac{1}{4}$ of section 23, T. 7 N., R. 3 E. The section is as follows:

	Feet.	Feet.
Clay	7 to 8	7
Sand and gravel	15	22
Sand rock	35	57
Slate (hard shale)	18	75
Coal	3	78

Under the coal in part of the mine is the clay, in part quite sandy. The shales contain nodules of carbonate of iron with sphalerite and pyrite, similar to those found at Grand Ledge and at the Standard Mine. For a description of this clay see Vol. VIII, Part I, page 27. Mr. Travis had mined in all directions from the shaft over 400 feet at the time of my visit, controls 300 acres, paid 5 cents to 8 cents royalty, and was getting \$2.00 a ton for block coal, \$1.60 for nut coal. The mine caters to what may be called a local and retail trade, but has recently been sold to the Twentieth Century Portland Cement Company. The coals dip sharply to

the N. E. as is shown by the fact that at the old shaft the coal is at a depth of only about 40 feet. This shaft is now used as an air shaft and an escape shaft. There is a break at the end of the south drift or entry, and the rooms to the west of it rise rapidly. Much water under a strong head comes in here. A bore hole going 75 feet below the coal gives a large supply of water with a strong head. The axis of the trough runs N. W. and S. E. Though this mine is near Kincaid's, it is said to be separated from it by a sandstone bar. This and the difference in quality lead me to think that they may be different seams; this one the Upper Verne (compare A4 and I4), and the other the Lower Verne. The sample for analysis was taken from the east side, the section being as follows:

Black shale	10 inches.
Coal (perhaps upper inch belongs above).....	2 feet 9 "
Sandy fire-clays.	

At the west end of the mine the section is somewhat as follows:

Shale with streaks of coal	8 inches.
Coal	32 "
Bone coal, "black jack"	7 "
Clay.	

There are fine *Stigmara verrucosa*=*S. ficoides*; also *Sigillaria* and *Lepidodendron* at this mine, but no ferns were noticed.

From the nodules D. White has noticed *Cordaites robbii*(?), *Cardiocarpon ovale* Lx., *Cardiocarpon bicuspidatum*, Sternb. var. *ohioense* D. W. and *Mariopteris cf. inflata*, and infers a probable equivalence with the Upper Pottsville or Sewanee zone. At the old shaft the coal was dipping 8 to 10 inches in 2 yards, and there was a black shale (soapstone) roof full of impressions of reeds and pyrite. In the grey shale above it the zinc nodules occur. The section was:

Gravel or sand.....	16 to 26 feet.
Alternating grey shales and sandstones to.....	61 feet.
Black shale.....	2 to 3 ins 61 feet 3 in.
Coal (2 to 4 feet).....	2 ? 63 feet 3 in.
Fire-clay.....	12 feet.

Analysis No. A5 (B5) is of a lump from the New Hope Coal Mine, Jackson, the main seam. No. A6 (B6) is of the top part, which I was told was somewhat different, but as we see, proves not essentially so. This mine is about two miles N. W. of the city limits on the S. W. part of section 21, T. 1 W., R. 2 S.

The mine, though in a small valley close to a county drain, is

nevertheless upon a moraine about 80 feet above Jackson city. The section exposed in the mine is as follows:

Black shale	top.
Top coal (analysis No. 6)	7½ inches.
Pyrite parting	½ "
Main coal (analysis No. 5)	32 "

There is considerable variety in the general section, and the coal lies in troughs which roll quite irregularly and more markedly southeastward, while to the N. W. it flattens out and becomes more regular, but the coal thins out and passes into black shale. Fifty feet west of the shaft the section is:

Surface	40'	
Slate	39'	79'
Coal	3' 5"	32' 5"

To the east the coal becomes more hard and sulphury and I think runs up against a normal fault which strikes N. N. W. There are said to be a number of cases in the Jackson field and one in this mine where reversed faults occur with a very flat hade, so that coal is shoved over the coal. The coal lies in a narrow trough not more than 150 yards wide, and several hundred long, so that when twenty years ago a hole struck coal here, other borings put down to test up failed to find it, and the project was then abandoned.

The output is about 60 tons a day, and as there is no railroad to the mine, the market is purely local, much being used in harvesting. The royalty was ten cents per ton on coal mined and sold. Screenings are not counted in computing royalty or wages.

The clay below the coal is soft for 4 or 5 inches, below that quite hard. A well is put down to 230 feet, mainly in white sandrock, with "soap rock" between that and the coal.

This is a coking gas coal (compare F7, G6, H4). I hardly think that Willcox's test No. 10, the exact location of which is not known, is of this coal.

Analysis No. A6 (B6) is of a lump from the top seam, which was supposed to be different. The high per cent of sulphur and low per cent of ash in this analysis made it seem probable that some of the sulphur was combined organically and not with the iron, as 3.07% S would imply 3.84% of Fe_2O_3 if the S all existed as FeS_2 and was all burned to Fe_2O_3 . So I had it analyzed by Mr. A. N. Clark, and the iron especially determined, and though the ash is slightly more, the Fe_2O_3 , as directly determined, would not yield enough iron to make FeS_2 with the S. It may be a question, however, in

view of Hilton's results, whether there is not an analytical error, or more probably an irregularity in sampling. If the S and Fe are not determined from identically the same sample, the pyrite is so much heavier than the coal, that it is not difficult to get $\frac{1}{2}\%$ difference. It is clear in any case that almost all of the S and ash of the analysis came from the pyrite.

Analysis No. A7 (B7 and D5) is from the Lower Verne, part of the Wenona coal seam,—not the best part, compare Analysis A12, and Plate IV.

This coal has also been analyzed by Dr. Koenig. His analysis is of both seams, and is rather better than ours. I took mine from the lower seam (Lower Verne) intentionally to see if there was any marked difference in comparison with his, especially in coking capacity. Mr. Williams reports a coke of small volume, well fused and of excellent quality. It is a true coking coal.

Analysis No. A8 (B8 and D6) is from the Verne (formerly Albee) Coal Co., N. W. $\frac{1}{4}$ of N. E. $\frac{1}{4}$ of Section 23, T. 10 N., R. 4 E. The coals here mined resemble the coals of the Wenona, Central and other Bay county mines, and I take them to be the same. In both cases there are two seams of coal close together, in both cases immediately associated with black shale containing marine fossils. It will be noticed also that in ratio of fixed carbon to combustible, this and the other analyses, A5 to A11, which I assign to these same seams, differ 10 points more or less from the Saginaw seams, but only $2\frac{1}{2}\%$ from the average, or are at extremes 5% from each other. Both coals are coking coals, but the lower is brighter and has less charcoal but more sulphur. The section is as follows:

Putty clay.....	16'	
Till hardpan.....	22'	38'
Sand.....	2'	40'
Shale.....	25'	65'
Coal at a depth of from 50 to 60 ft.....	3 $\frac{1}{4}$ '	68 $\frac{1}{4}$ '
Upper coal with much charcoal.....		34"
Slate.....		7"
Lower coal, brighter.....		6"
Fire-clay or shale below.....		

A well goes on to 75 feet and draws somewhat mineral water, while a well not far off has soft, not salty water at 107 feet.

Analysis No. A9 is of the Sebewaing coal, a large sample taken from the pile of the Michigan Standard Coal Mining Co. by Prof. H. Ries. They struck 4 feet 9 inches of coal at 92 feet depth and have from 7 to 17 feet of slate roof. Compare the records of numerous holes given in Vol. VII, Part II, in this neighborhood, and Figures 10 and 11 of that report, reproduced here as Figures 3

and 9. Analyses F1 and F6 are from other mines near by in the same seam, and agree in indicating considerable sulphur and a high percentage of gaseous matter.

Analysis No. A10 (B10 and D8) is taken from the mines of the Michigan Coal and Mining Co. (J. A. Etzold, Pres.), on the N. W. $\frac{1}{4}$ of the S. E. $\frac{1}{4}$ of Section 25, T. 14 N., R. 4 E. In this mine we have two coals, of which the lower was worked at the time of my visit (at present I understand the upper only is shipped), which was at an early date, Sept. 20, 1899, when the mine was only out 500 feet to E and not so far W. It is about 122 feet down through the lower coal. At the east end of the mine the two coals approach, and there is but three feet between them. The upper coal is more wet and gassy, but of better quality, apparently. See tests at Lansing Water Works in 1901, and also J3. A section is as follows:

Clay.....	72'		82'
Till.....	10'		91'
Shale.....	9'		94'
Extra hard (FeCO ₃).....	8'		106' 6"
Slate and shale with Lingula shale.....	12' 6"		109' 6"
Upper Coal (Upper Verne).....	2' 6"		118' 7"
Shale and Slate fossiliferous.....	9' 7"		121' 4"
Coal (Lower Verne).....	3' 9"		122' 7"
Fire-clay.....	3'		

The shells found here are largely the same as found at the Verne Mine. See p. 42.

Analysis No. A11 (B11) is from the Central Coal and Mining Co. on S. E. $\frac{1}{4}$ of the S. E. $\frac{1}{4}$ of Section 25, T. 14 N., R. 4 E., i. e., joins the Michigan Mine just described so that one escape shaft serves for both. As the analysis shows, this is of the same quality as the Michigan lower seam. It is here also the lower seam, 125 to 130 feet down, the section being somewhat as follows:

Clay.....	78'			109'
Till.....	31'			112' 4"
Shale.....	3' 4"			115'
Coal.....	2' 8"			120'
Sandrock (?).....	11'			133'
Black shale.....	7'			133' 5"
Bone coal.....	2' 5"			138' 11"
Coal.....	2' 8"	3'	6"	
White sandy fire-clay.....				

Analyses Nos. 7, 8, 9, 10 and 11 appear to be all from the same seam, the Lower Verne. As contrasted with the Saginaw seam, they are all high in ash, sulphur and volatile matter, but not coking coals, while the latter is low in ash, higher in moisture and not ordinarily, at least, coking. Analysis A12 is of the Upper Verne, in the Wenona Coal Mine, Bay County, and of better quality.

Lower Verne

Upper Verne



UPPER AND LOWER VERNE SEAMS, WENONA COAL MINE.

1

1

(B). Analyses by H. J. Williams, referred to dry coal.

Table B refers to the same analyses as Table A, but the percentages are all referred to dry coal, thus eliminating that uncertain element, the moisture.

(C). Analyses for comparison by H. J. Williams.

Table C gives the results of analyses and tests on a number of standard coals by H. J. Williams for comparison. The proximate analyses refer to the coal as it came, but the ultimate analyses and heating power tests refer to dry coal. In the case of the Pocahontas coal, however, C4, there is very little moisture anyway. This is perhaps the best standard coal to use for comparison. For instance, it is included in the Lansing Water Works and in Willcox's tests, and Willcox's Calorimeter results agree with Williams' to within 2%. While, according to the calorimeter tests the Michigan coals run from 80 to 90% of the heating power of the Pocahontas (p. 105), practically they yield about 65% to 75% as much, so much heat escaping up chimney in the evaporated moisture of the coal, etc.

C1. "Big Muddy" coal from Cartersville, Williamson Co., Ill.

C2. Pittsburg coal. Average of four analyses and tests. Compare the analysis of Pittsburg coal by Wuth and Stafford, with which F8 is compared.

C3. Clearfield, Pa.

C4. "Pocahontas" coal,—A West Virginia Coal.

C Nut coal. Mount Olive, Macoupin Co., Ill.

K Kinkad, a Hocking Valley coal, average of two analyses.

Y Yorkville, lump and fine.

C It will be noticed that the best semi-bituminous coals give from 14,500 to 15,000 B. T. U., while the good bituminous run from 13,000 to 14,000 B. T. U. for dry coal. It follows by comparison that the heating power of the Saginaw seam is extra high when referred to dry coal, the weak point being the amount of hygroscopic moisture, for a bituminous coal.

(D). Analyses by C. H. Hilton.

Table D gives the results of analyses by C. H. Hilton, on material largely the same as Tables A and B. These analyses were performed as thesis work in the Michigan Agricultural College and published in the Michigan Miner for August, 1900.

Samples Nos. 1 to 4 were carefully taken from the material returned by H. J. Williams, with corresponding numbers. (D1 to

D4=A1 to A4, respectively.) Analyses D5 to D8 correspond to A7 to A10.

D9 is from Grand Ledge, about the same material, perhaps not so carefully subdivided as E3,—a lump from Jenkins' drift on Coal Creek almost beneath the pits, the shales of which are exploited by the Grand Ledge Sewer Pipe Co., Frank A. Taber, secretary. Quite a full description of this region was given by Rominger.*

The sewer pipe works are close to the N. E. corner of Section 10, T. 4 N., R. 2 W., and the material is mainly derived from a shale from a pit about a quarter of a mile N., close to the Spiritualist camp grounds, at the summit of a bluff overlooking Grand River and a small tributary. The section here exposed is:

- 3 ft. stripping of till.
- 4 ft. shale, gray, with nodules.
- 1 ft. black shale verging into coal.
- 2 ft. white clay, so called fire-clay. The lower boundary of this white shale undulates so as to indicate that this is merely the shale below altered.
- 4 ft. blue clay, with large nodules of siderite and some zinc blende, and traces of ferns.
- 1 ft. darker shale, the floor of the shale quarry. Passing to the east into the Boyle's Mine Coal (horizon of Upper Verne?).
- 20 ft. light and dark thin bedded sandy shales and sandstones, slaking up on weathering.
- 1½ ft. coal, which is the coal analyzed (Lower Verne?). White sandstone.

The analyses of the darker and lighter shales are given in Part I. South of the works there is also a pit which lies much lower, in the valley of a stream and filled with water, and as the dip of the beds appears to be a little to the north, if anything, it is probably stratigraphically lower. The section is:

- 15 feet cross-bedded sandstone.
- 3 feet coal, with black shale and *Lingula mytiloides* just above.
- 3 feet white shale which I am told is the layer which is sometimes used. It is of different quality from the other, and the pit is generally filled with water. The shale here is much richer in ferns. (See p. 44.)

The coal workings consist of a series of little adits or drifts very irregularly driven in the bluffs facing the Grand River and mainly on the south side about ten to fifteen feet above the stream. Next to the northernmost with thickest coal is Pratt's coal mine, the adit being about 300 feet in, and the coal 28 to 30 inches thick. The next worker south is Chas. Hodge, then Wilkinson, then two other little openings, then the Jenkins old drift under the clay pits, and there is a new shaft on the Spiritualist Camp Meeting Grounds, put down by F. Boyle to the upper seam.

D10 is from drillings of a thin seam of coal near Pinconning, S.

*Geological Survey of Michigan, Vol. VII, Part I, p. 131.

E. ½, Sec. 10, T. 17 N., R. 3 E., about 150 feet down, obtained through Mr. R. J. Mansfield.

D11 is from the Rifle River cannel coal, Sec. 3, T. 19 N., R. 4 E., about the same as G4 probably, though not identical samples. The coal is a cannel coal of very light specific weight, conchoidal fracture and little or no lamination, associated with *Lingula* shales, and showing no sulphur to the naked eye, so that the amount that the two analyses show is surprising. Upon exposure to air and moisture alternately, however, a white coating of iron sulphate soon forms. The section is quite fully described by Rominger,* as follows:

Disturbed material, drift	14	14
Hard calcareous sandrock	3	17
Black slate, with <i>Lingula mytiloides</i> and fish remains and cannel coal	10	27
There is also a lower seam (see analysis G5).		

Mr. Hilton's notes on his work are as follows:

"It will be noticed that the moisture and volatile combustible matter are uniformly lower in my determination than in the original analyses by Williams. Inasmuch as the amounts of these two factors had little bearing upon the present investigation, I made the determination of them together. To get at as to where the loss came in I made moisture determinations on three samples and found the loss of moisture accounted for the loss in the total moisture and volatile matter. Without going further, I took it for granted that the loss was thus accounted for in every case. The loss in moisture necessitates a higher proportion in the constituents, and I find accordingly larger percentages of total sulphur and of ash. The amount of sulphur in the ash is very small and is considered as sulphate in the coal. The amounts of volatile sulphur agree quite closely in the two sets of analyses.

"So far as the investigation has been carried the determination of iron has been the significant feature. I would call attention to the peculiar relation the content of iron bears to the content of sulphur. One varies as does the other, and they stand in almost exactly the same relation to each other in every instance, viz., in combining proportion 56+64.12 to form iron pyrite (FeS_2).

CONCLUSION.

"As we stated in the introduction, the work has not been carried to its farthest analysis; and whatever conclusions are drawn must be stated as strongly indicated and not as absolute or positively demonstrated. But there is a strong probability, amounting almost to a certainty, that the sulphur is all accounted for correctly.

"First. A small amount of sulphur is non-volatile, being found as sulphate with calcium. Gypsum is found in perceptible amounts in coal deposits and the non-volatile sulphur is thus easily accounted for.

"Second. That the volatile sulphur is all combined with iron in the form of iron pyrite (FeS_2).

"This second conclusion is given weight by the fact that in all the samples analyzed, all the sulphur and nearly all the iron are accounted for by combining them as FeS_2 . It can easily be seen how, in one or two instances, these proportions would occur by accident and thus lead to erroneous conclusions. But it is extremely improbable that this accidental relation would occur in every case of samples of coal taken from eleven different mines in widely separated parts of the State. It seems just, therefore, to conclude that the volatile sulphur is rightly accounted for as FeS_2 . This is not saying that the iron and sulphur were originally deposited in these proportions. But that does not concern this investigation. The present condition in the coal is what I am after."

I called Mr. Hilton's attention to the well known fact that bi-carbonated waters containing gypsum will, in the presence of organic matter, yield H_2S freely. This would turn iron salts into sulphides.

*Vol. III, part I, pp. 141 and 142.

"One or two interesting observations may be added. The coals are to all appearances perfectly dry, yet when they are subjected to a temperature of 100°C for one-half hour they lose 5 to 10% of their weight. The coal beds all being in valley regions and surrounded by higher grounds, have been for ages subjected to a strong hydrostatic pressure, which may account for the large content of hygroscopic moisture. Even after being handled about and kept in a comparatively dry place for some time, these coals yet yield as high as 8% moisture."

METHODS OF ANALYSIS.

"Sulphur.—The method used for determining sulphur was a modification of Eschka's method and has been already described. (P.60.)

"Ash.—Ash was determined by burning off in the muffle $\frac{1}{2}$ gr. of coal placed in a tared platinum dish, then weighing.

"Iron.—The ash from each determination for ash was thoroughly digested with strong hydrochloric acid, c. p. to dissolve out the iron. The HCl was then expelled with H_2SO_4 . The solution of ferric sulphate was then run through a reductor and immediately titrated against a previously standardized solution of KMnO_4 .

"Moisture and Combustible Matter.—I placed 1 gr. coal in tightly covered platinum crucible; heated over the Bunsen flame $3\frac{1}{2}$ minutes, then over the blast lamp for another $3\frac{1}{2}$ minutes. The loss is moisture and volatile matter. The determination of ash, moisture and volatile matter had little direct bearing upon the present subject. I made them to satisfy myself that the coal was practically of the same composition as it was in the original analyses. The samples had been handled considerably and it was thought there might be a loss of volatile matter accompanying a slight loss in moisture."

The origin of the investigation was as follows:

In looking over some of the analyses of Michigan coals made for me, for instance A6, it was noticeable how low the ash was compared with the sulphur, so low indeed that if we estimated that all the iron which was combined with sulphur in pyrite (FeS_2) remained in the ash oxidized into ferric oxide there must be some sulphur which was not combined with the iron. So I suggested to Mr. Hilton for a thesis to work over some samples which I gave him to see if this were really so by determining how much iron was really present. It should be explained that between analysis and re-analysis they had been some weeks in bags and boxes before being separated and put into smaller jars. The samples originally taken, largely by myself, weighed twenty-five pounds or more, and were divided after returned from Boston and analysis by H. J. Williams into lots of about a pound. Thus, though the usual pains were taken in dividing, the samples had considerable chance to lose moisture and organic gases, and might vary a little in quality in the division. On the whole the re-analysis agrees with the original analysis remarkably well and entitles both to a good degree of confidence. They indicate also the amount of variation which may be expected in analyses owing to variation in sampling and in the time between the taking of samples and their analysis.

It will be noticed that if Mr. Hilton had determined the moisture separately from the volatile matter throughout, he would have made complete proximate analyses, for by subtracting the amount of the ash and volatile matter from 100 we obtain the per cent of fixed carbon.

In regard to the relation of the ash and the iron, it may be noted that if all the iron were in the ash as Fe_2O_3 , there would be 3.7ths more Fe_2O_3 in the ash than iron as given, and we see that in a number of cases the ash must have been practically all Fe_2O_3 . But unless great and especial care is taken the iron will not be completely oxidized, but will appear in a metallic or magnetic shape. This, Mr. Geo. B. Willcox informs me, also has been his experience, and in such case of course the iron will not form so large a proportion of the ash.

The most important results of Mr. Hilton's investigation seem to me to be two. First, he has shown what a very small proportion of clay ash is in some of our Michigan coals. And in the second place, his results show that there is no sulphur in excess of that required to combine with the iron, but that they are almost in exact proportion, so that if we find the amount of iron in the coal and add one-seventh we shall find the amount of sulphur within a fraction of a per cent.

As it is far more easy to determine the amount of iron quickly and accurately than the amount of sulphur, this may be of practical value to the chemist. It suggests also that the sulphur was not there originally, but was precipitated by the iron, which was there first. The later statement is easy to receive and believe for bog iron deposits are common in connection with peat and muck deposits, and nodules of carbonate of iron are quite common in the coal measure shales. Now the waters of the coal measure shales are strongly bicarbonated, and beneath the coal measures are beds of gypsum, with which many of the coal measures are impregnated. It is a well known fact that if in bottling any carbonated waters containing gypsum any organic matter, such as a wisp of straw, should get in, H_2S is generated, a gas which would have power to convert the bog iron ore into iron sulphide.

It is also likely that iron sulphate has been reduced by the organic matter of the coal to iron sulphide. Finally, there seems to be a division into two groups of analyses; one low in sulphur, and another high, the percentages not being evenly distributed. This probably corresponds to the fact that the samples come from at least two distinct seams.

(E). *Analyses by A. N. Clark.*

The three analyses made by A. N. Clark, of the Michigan Agri-

cultural College, in this table were also intended to throw some light on the same problem as Hilton's.

E1 is of the same sample as A1 and D1.

E2 is of the same coal as A6.

E3 is of the same coal as D9.

E1 and E2 would lead one to infer an excess of S over that required for sulphide of iron, but in view of the other analyses on the same samples, it appears likely that the results in sulphur are too high. This is probably due to the chemicals used in analysis not being free from sulphates. Mr. Hilton found the same difficulty in the beginning of his work,—the sodic carbonate supposed to be chemically pure, not proving such. The analyses otherwise agree quite well though made by different chemists, and the moral I would draw is the advisability of iron determinations as a check on the sulphur determinations.

(F). *Proximate Analyses.*

Table F includes a number of proximate analyses by various chemists. The accuracy of these we do not guarantee. As reported to me the sulphur is included in the summation to 100%, and in all probability to make room for it from the per cent of volatile combustible found as above described (p. 62), one-half of the per cent of sulphur found is subtracted, and the other half from the fixed carbon. Therefore, to make them more comparable with analyses of Table A, I have added what the original figures for the volatile combustible and fixed carbon probably were.

F1. Sebewaing coal, probably from the mines of the Saginaw Bay Coal Co., at 80 to 90 feet depth, on section 18 of Sebewaing, T. 15 N., R. 9 E.

E. Speidel analyst, Twelfth Annual Report of Saginaw Board of Trade,—also our reports, Vol. V, Part II, p. 84, and Vol. VII, Part II, p. 218.

The following is a typical record from the neighborhood (Vol. VII, Pt. II, p. 150):

Sand.....	3'	
Clay.....	39'	42'
Hardpan.....	3'	45'
Sandrock.....	26' 4"	71' 4"
Coal, about.....	5"	71' 9"
Sandrock.....	8'	79' 9"
Slate.....	6"	80' 3"
Sandrock.....	7' 1"	87' 4"
Coal (analyzed).....	4'	91' 4"
Light shale.....	3"	91' 7"

While the following, being near by, shows the relation also to the underlying strata:

Pleistocene.....	{ Clay	51'	
	{ Sand and gravel	1'	52'
	{ Loose sandrock	2'	54'
	{ Hard rock	2'	56'
	{ Dark sandrock	18'	84'
Coal bearing series (Pottsville?)	{ Coal, about	1' 6"	74' 6"
	{ Sandrock	1' 6"	76'
	{ Slate	6'	82'
	{ Coal (analyzed)	3' 8"	85' 8"
	{ Bottom slate	1' 4"	87'
Parma (?).....	{ Sandrock	13'	100'
	(Somewhat water bearing.)		
	{ Light slate or sand fire-clay	96'	196'
Grand Rapids.....	{ Hard dark rock (dolomite)	24'	220'
	{ Slate	20'	240'
	{ Hard lime rock	8'	248'
Napoleon (Upper Marshall.)	{ Sandrock	55'	30'

In analysis this coal resembles the Lower Verne, and the occasional presence of another coal not far above it is significant.

This and F6 have the high volatile combustible and sulphur of the Verne seams though the volatile combustible is almost *too* high, and the ash must be almost wholly iron oxide from the iron sulphide. The samples may have been select lumps. Analyses A9 is probably of the same coal, but was taken by H. Ries unselected from the pile at the tipple.

A section of the coal seam at one point in the Sebewaing Coal Co.'s mine was:

Bone coal (burns but retains its bulk after burning, heavy)	0' 4"
Marcasite	0' 1"
Main coal	5' 0"

Mr. Chas. Holmes says: "Pyritic iron is distributed throughout the coal, reaching in quantity as high as 25% of the coal seam, and masses of it called boulders by the miners, in cubical crystals are found in the raw state. But while the amount of sulphur in the form of iron pyrite is undesirably high in this coal, which lessens its value by the formation of sulphide of iron and tenacious clinkers which have a tendency to destroy grate bars, still in furnaces where proper appliances have been used to overcome this objectionable feature, the coal has proved of high value for heating purposes."

F2. An old analysis of the Corunna coal from the Twelfth Annual Report, Saginaw Board of Trade. This is of the coal of the Corunna Coal Co., Tod Kincaid, manager, on Sec. 13, T. 7 N., R. 3 E., the same as F5 and G3. Inferior both in ash and sulphur to A4, which is near by at about the same depth.*

*I suspect that this is the Lower Verne coal from the analyses, and the fact given me by Mr. W. H. Hess that the roof is largely limestone, seems to be confirmatory.

F3. One of the first analyses of Saginaw coal, by A. W. H. Linders. It is cited with comparative boiler tests of Saginaw and Hocking Valley coal. Evidently the moisture had been driven off beforehand, and probably a little of the volatile combustible, and we cite it mainly to call attention to the fact that it is not an analysis of the natural coal.

F4. Analysis made by Heim Bros of Saginaw, for the Saginaw Clay Mfg Co., is supposed to be of the coal which was mined incidental to their shale work at Flushing. S. W. $\frac{1}{4}$ of Sec. 22, T. 8 N., R. 5 E. A view and description of their quarry is given in Part I. The general type of this analysis is that of the Saginaw seam,—high in moisture and fixed carbon and low in volatile combustible and sulphur. Borings on Sec. 15 and elsewhere in the neighborhood, however, show that there are at least 216 feet of coal measures here and indicate a higher position for it.

Compare analyses J7, 8 and 9, of drillings near by.

F5 is of the Corunna Coal Co. coal, an analysis furnished by T. Kincaid. Compare F2 and G3. The exact seam from which these analyses come is not well known.

F6 is of the Saginaw Bay Coal Co., coal at Sebewaing, by W. H. Coffron. Compare F1.

F7 is an analysis of Jackson cannel, quoted by A. Winchell 1861.

The large amount of volatile combustible is noteworthy and A5 and A6 are much like it, except that they have more water and less volatile combustible, and less sulphur. The former difference may be due to the analyst.

F8 is an analysis furnished by Wuth & Stafford in connection with the report cited above p. 64* on the availability of the Saginaw coal for a gas coal. Comparing this analysis with A1 to A3 the lower amount of moisture is noteworthy. This appears to be due to the imperfect separation of the moisture from the volatile combustible. The amount of S is also abnormally low.

(G). *Partial and proximate analyses of recent date.*

G1. By Prof. C. A. Davis, for O. W. Blodgett, of a coal from 89 to 110 feet down, supposed to be a pocket of drift coal, near Munger.

G2. Average of nine analyses by students under F. S. Kedzie, of a piece of drift coal from Scotts, Kalamazoo county.

G3. Corunna Coal Co., average of 13 analyses made by students of Prof. F. S. Kedzie at the Agricultural College.

*Also Michigan Miner, May, 1901, p. 17.

G4. Rifle River cannel coal, Analysts Dickman and MacKenzie, No. 8615. Through S. G. Higgins, Esq.

This is practically the same material of which D11 is an analysis, and the sulphur and ash check quite fairly. The material has a conchoidal fracture and a little lamination and occurs in association with Lingula shale. Near the river it is said to be but 17 feet down to this coal.

Beneath this cannel coal is said to be the seam of bituminous coal represented by G5.

I do not feel absolutely certain, but in all probability this analysis fairly represents the coal of the Eureka Coal Co., of which the following test by Geo. F. Sherwood of the Jackson Gas Works is given in the Saginaw Evening News of July 23, 1898:

Charge of coal 4,800 lbs.
Gas 15,600 cu. ft.
Burns freely with no clinkers, and makes a very hot fire.

G5. Rifle River coal, lower seam, a single lump, by T. C. Phillips, at the Agricultural College, for E. C. Sovereign.*

G6. Jackson coal, Rominger, agrees very well with A5 and is in showing that the coal at Jackson mines has over 40% of volatile combustible, and is a gas coal.

G7. Analysis of black shale from near Alpena, through W. H. Johnson, showing the real character of the stuff which often starts coal excitements. Analysis of the ash will be found in Part I of this volume.

G8. Is an analysis of the five feet of coal shown in the following record from Sec. 13, Bingham Township, Clinton county, T. 7 N., R. 2 W., by Prof. F. S. Kedzie for M. H. Kniffin.

Surface	103	103
Sandrock	7	110
Clay, some coal	2	112
Coal	5	117
Limestone	7	124
Coal	1½	125½

(H). Analyses by Bradley and Reed.

The analyses of this table were made by Mr. F. F. Bradley mainly; Nos. 1 to 6 at Alma, and with the assistance of Prof. C. A. Davis.

H1. Was reported as from the Verne mine, St. Charles. The

*This agrees quite fairly with older results (See Saginaw News July 19, 1898), less than .75 S., and 4½% ash. A shaft is said to have gone down to this seam and found it 4½ feet thick and of good quality.

analysis is distinctly that of a St. Charles coal, the Saginaw seam, and not one of the Verne coals. Compare A3.

H2. From the Standard mine, Saginaw. Compare with A2.

H3. From the Valley coal mine (Dutch Creek coal) near Bay City, as I suppose from the Monitor seam.

H4. From the New Hope mine, northwest of Jackson, should be compared with A5 and A6, which it resembles in proportion of volatile and fixed combustible.

H5. From the Trumbull mine, is of a shaft worked only a short time, northwest of the old Woodville mine, five miles from Jackson, Sec. 24, T. 2 S., R. 2 W., and is only a partial analysis.

H6. From the Wenona mine, Bay City, agrees pretty well with G2, but not so well with A7.

This mine has the following sections:

Clay.....	74'	
Sandrock.....	9'	83'
Shale (see Part I of this Vol.).....	37'	120'

Black shale, with *Lingula mytiloides*, which also occurs abundantly at the air shaft, is the base of this shale.

Coal, lineations well marked with much dull charcoal.	3'	6" to 2 ft.
Parting of shale and sulphur streaks.....		10"
Coal (as sample) brighter, more pitchy in luster....	3' to 2'	
Fire-clay, very siliceous clay shale, passing into a fine grained sandstone.....		
The coal is at a depth of 130 to 140 feet and the two coals are shown in Plates IV and VIII. Compare analyses A7 and A12.....		

The lower bright coal I take to be the Lower Verne, while the upper dull coal may be the Upper Verne or Monitor coal.

Going east 1,300 feet a 10-inch coal comes in on top of the upper seam. Where first seen it is 3 to 4 feet above, separated by a white sandy clay and gradually getting down to within 10 inches of it.

Compare this with the section of coal reported at Handy Bros.' Mine:

Coal, rusty with a few inches FeS ₂ at top.....	3'	6"
Parting, few inches.		
Coal, brighter, shinier, not as hard as upper coal, some FeS ₂ at bottom.....	1'	6"
Parting.....		4" to 11"
Coal.....	1'	

The bed rock is at 75 to 80 feet depth, the coal is at 110 to 120 feet or less, but there are 20 to 18 feet of roof shales.

H7 and H8. By F. F. Bradley and Reed of Chicago University, are from the same sample, taken from the Pere Marquette No. 1 shaft, as A1, B1, D1, E1. Analyses H7 and H8 are slightly better in most respects. The loss of moisture may be due to drying, possibly.

H9. By F. F. Bradley, is of the same sample as A9.

H10 and H11 are by Reed and F. F. Bradley, of the same sample as A10.

This suite of analyses do not agree satisfactorily with duplicates and suggest the question how much variation can be produced in reducing from the large sample taken to the small sample analyzed, and how much is due to difference in chemical manipulation.

The suite H runs steadily high in fixed carbon, yet if we compare A1 with A9 we find that H8 and H9 are similarly related, so that the relative behavior of the coals is the same.

(I). *Recent Analyses.*

Table I contains a number of recent and quite reliable proximate analyses, which are mainly accompanied by calorimetric tests.

I. This was an analysis by J. D. Pennock of a barrel of coal cut from the bottom to the top of the seam, at the mine of the Saginaw Coal Co. N. E. quarter of Section 31, Buena Vista township, T. 12 N., R. 5 E. It yielded 10,600 cu. ft. of gas, 110 lbs. of tar, 19.6 lbs. ammonia sulphate, and 54.50% of very good light coke, which analyzed:

Volatile matter	1.0
Fixed carbon	92.2
Ash	6.8
	<hr/>
	100.0
Sulphur .....	.9

This was analyzed at the Solvay Co.'s works at Syracuse.

A record of the section at the mine is as follows:

Clay	54'	
Sand and gravel, which turned out in the shaft to be a diagonal streak of a few inches	3'	57'
Clay	37'	94'
Sand	4'	98'
Hardpan to bedrock	5'	103'
Slate	1'	104'
Coal, Lower Verne?.....	1"	104' 1"
Gray slate	18'	122' 1"
Slate	6' 6"	128' 7"
Coal, Middle rider?.....	4"	128' 11"
Hard sandy clay	1'	129' 11"
Gray shale	5'	134' 11"
Strong black shale	12' 2"	147' 1"
Coal, this is the coal mined (Saginaw seam).....	3' 3"	150' 4"
Fire-clay	18'	168' 4"
Sand rock	34'	202' 4"
Sandy shale	3'	205' 4"
Slate	16'	221' 4"

This is a little south and about 1,700 feet east of the north quarter post of Sec 31, T. 12 N., R. 5 E.

This coal analyzes like the Pere Marquette, Somers, and other coals of the Saginaw seam and as such I take it. It rises rapidly to the Pere Marquette No. 1, and a little further east plays out against a big sandstone. The high per cent of moisture is characteristic, shown also in I3 and I4, and it is not superficially wet, but hygroscopic.

Analysis I2 was of a carload of slack with much sulphur and slate, which did not make a good coke—all came out in a fine slate. It was impossible to drive off the last traces of gas. The coal yielded very little bituminous matter, a small amount of tar (25.10 lbs. per ton), 59.15% of a soft useless coke, of sulphate of ammonia, 17.40 lbs. per ton, of gas 10,000 cubic feet. Analyzed by J. D. Pennock, Feb. 17, 1899.

Analysis of coke:	
Moisture	3.2
Volatile matter	7.03
Fixed carbon	66.02
Ash	23.75
	<hr/>
	100.00
S.	2.097

These analyses illustrate a general principle, that with the introduction of slate or bone coal represented by ash in the analysis, the fixed carbon drops faster than the volatile.

This analysis of slack is of course of no value as indicating the quality of the coal and there is more slate than usual in the marketed product. But it is very interesting, owing to the fact that less moisture appears than in the coal J1, or the coke. The idea suggests itself that the slate and the sulphur can hold back the moisture which would otherwise be given off by the coal.

I3 and I4 are duplicate analyses of a sample taken by T. Pray, of Boston, in December, 1899, from a car of Saginaw coal, and analyzed at Cornell University. The calorimeter results are obtained by Mahler and Carpenter Calorimeters (p. 52).

I5 and I6 are derived from I3 and I4 by computation for dry coal, and I7 and I8 similarly for combustible.

These analyses show the largest amount of moisture of any quoted, though they are nearly equaled by some of Williams', e. g., A1 and A2.

Mr. Pray says, however, that the moisture is not surface moisture or snow, but an essential part of the coal. This burned up freely but soon lost its heat.

I9 is of drillings and I10 is of a lump coal from the Robert

Gage Coal Co.'s shaft at St. Charles, on Section 10, T. 10 N., R. 3 E. I suppose the samples to be from the same seam as A3. The analyses were made at the M. A. C. laboratory, and the calorimeter tests made with the Parr Calorimeter. The same puzzling and important discrepancy in moisture to which we have already referred, appears.

I11 is of a lump from the top eight inches of "bone coal" from the same seam. It will be noticed that it has no more ash than A7, 10 and 11, H9 and J6, and that the ratio of fixed carbon to combustible is that of the main seam, I10.

I12 is of fragments of an upper coal, one of the Verne coals encountered in sinking the shaft of the St. Charles Coal Co.

(J). *Supplementary analyses.*

Table J contains some coal analyses 1 to 6, by Lathbury and Spackman, which we owe to Mr. U. R. Loranger. They are all from the neighborhood of Bay City and all probably from the Verne seams.

J3 is from the upper seam at the Michigan Coal and Mining Co.'s mine. Compare A10. It shows clearly how much better is the upper seam which they are now working, the upper Verne.

J4 is from the old Monitor mine, I take it, from the same seam.

The other samples are from undeveloped drillings, and the high percentage of ash is doubtless in part due to the admixture of slate.

J1 and J2, and J5 and J6 resemble in a general way A10 and A11, and are probably from the same seam. The ratio of fixed carbon to total combustible is lower than in the Saginaw seam.

J7, J8 and J9 are analyses by H. J. Williams of samples of drillings supposed to have come from near Flushing, which had been kept for quite a while, and are probably from two different seams.

(K). *Peat analyses by W. H. Allen.*

The analyses of this table are of peat, and were made by Prof. W. A. Allen of the Detroit College of Medicine for the Chelsea Compresso Peat Co., of Detroit and Chelsea, Mich. No sulphur is reported. It is generally absent in peat. The percentage of moisture, which has not been separately determined, would probably vary from 10% to 25%.

TABLE A.—ANALYSES BY H. J. WILLIAMS.

Number.....	1	2	3	4	5	6	7	8	9	10	11	12
Location.....	Pere Marquette, No. 1.	Standard, Saginaw.	No. 1, Somers, St. Charles.	Orosco.	New Hope, Jackson.	New Hope, Jackson.	Lower Verne, Bay Co.	Verne.	Sebewaing.	Michigan Lower Verne.	Central Lower Verne.	Upper Verne, Bay Co.
Sp. Gr.....	1.260	1.260	1.285	1.27	1.247	1.244	1.22	1.22	1.24	1.23	1.26	.....
Moisture.....	10.15	10.67	7.79	7.55	5.58	5.23	8.71	5.82	6.09	5.01	4.52	3.78
Volatile Comb.....	33.14	32.59	34.74	35.70	45.73	45.59	38.45	39.79	32.54	39.62	40.57	41.18
Fixed Carbon.....	53.95	53.80	52.58	52.96	45.28	44.64	41.16	45.15	46.06	41.87	42.16	49.34
Ash.....	2.76	1.94	4.89	3.76	2.41	2.84	11.68	9.24	8.26	13.70	12.75	5.70
Sum.....	100.000	100.000	100.000	100.000	100.000	100.000	100.000	100.000	100.000	100.000	100.000	100.000
Total S.....	1.10	1.01	1.01	1.50	2.83	3.07	2.72	3.83	5.72	6.66	6.92	2.50
S. in ash.....	0.10	0.06	0.19	0.02	0.01	0.02	0.17	0.09	0.04	0.29	0.05	0.47
Volatile S.....	1.00	0.93	0.82	1.48	2.82	3.05	2.55	3.74	5.68	6.37	6.87	2.03
Iron 7-8 of volatile S.....*	.87	0.82	0.79	1.29	2.46	2.66	2.23	3.27	4.97	5.57	6.01	1.78
Fe ₂ O ₃ 6-4 of volatile S.....*	1.25	1.17	1.02	1.86	3.52	3.81	3.18	4.57	7.10	7.96	8.58	2.58
Clay (ash—Fe ₂ O ₃).....*	1.51	0.77	3.87	1.91	n 1.11	n 0.97	8.50	4.87	1.16	5.74	4.17	3.17
Maroasite 6-8 of S.....*	1.87	1.75	1.61	2.87	5.23	5.71	4.78	7.01	10.65	11.94	12.88	8.81
Corrected C.....*	53.88	53.69	52.40	52.66	44.94	44.30	40.88	44.68	45.40	40.87	41.29	49.08
Hydrocarbon.....*	32.64	33.12	34.33	34.95	45.32	45.07	37.18	37.92	36.70	36.44	37.14	40.16
C.....	71.11	71.67	71.37	72.88	73.55	72.42	65.87	68.33	66.07	62.39	63.57	73.09
H.....	4.74	4.90	4.48	4.81	5.77	5.78	4.90	5.00	5.26	4.68	4.78	5.03
N.....	1.40	1.40	1.40	1.45	1.50	1.50	1.01	1.25	1.49	1.30	1.19	1.31
O.....	8.84	8.49	9.25	8.04	8.37	8.53	5.23	6.62	5.15	6.80	6.80	9.06
Heating Power by Williams' Calorimeter in B. T. U.....	12,720	12,868	12,886	13,016	13,569	13,562	12,859	12,861	12,714	12,012	12,059	13,489
Calculated from ultimate analysis by Dulong formula	12,698	12,876	12,806	13,099	13,755	13,561	12,335	12,702	13,037	11,681	12,085	13,189
Heating Power in B. T. U. calculated from proximate analysis.....	12,783	12,810	12,798	13,025	13,540	13,479	11,760	12,670	12,767	11,965	12,408	13,370
"H" in B. T. U.....	147.47	149.50	148.25	144.04	160.44	151.77	158.37	160.67	164.39	167.39	168.79	.....

TABLE B.—ANALYSES OF MICHIGAN COALS BY H. J. WILLIAMS, REFERRED TO DRY COAL.

Number.....	1	2	3	4	5	6	7	8	9	10	11
Volatile Comb.....*	38.9	37.6	37.7	38.6	49.5	49.5	42.1	42.2	42.2	41.7	43.5
Fixed Carbon.....*	60.0	60.2	57.0	57.3	48.0	47.5	45.1	47.9	49.0	43.8	44.2
Ash.....	3.07	2.17	5.30	4.07	2.55	3.02	12.79	9.81	8.79	14.42	13.3
Volatile S.....	1.11	1.04	0.89	1.60	2.99	3.24	2.80	3.97	6.04	6.71	7.2
C.....	79.14	80.23	77.40	78.86	77.90	76.98	72.16	72.55	72.49	65.57	66.6
H.....	5.28	5.48	4.86	5.20	6.11	6.09	5.37	5.31	5.61	4.87	5.0
N.....	1.56	1.57	1.52	1.57	1.59	1.59	1.10	1.33	1.59	1.26	1.2
O.....	9.84	9.51	10.03	8.70	8.86	9.08	5.73	7.08	5.49	7.17	6.6
	100.000	100.000	100.000	100.000	100.000	100.000	100.000	100.000	100.000	100.000	99.9
Heating Power per unit dry coal calculated from result by Bomb Calorimeter.....	14,164	14,405	13,920	14,083	14,371	14,353	13,527	13,656	13,588	12,646	.....

* Computed from analysis by A. C. Lane.

TABLE C.—ANALYSES FOR COMPARISON BY H. J. WILLIAMS.

Number.....	1	2	3	4	5	6	7
Location.....	Big Muddy.	Pitts- burg.	Clear- field, Pa.	Poca- hontas.	Mt. Olive Nut.	Hocking Valley.	York- ville.
Moisture.....	5.79	1.49	0.44	0.55	4.82	5.42	1.44
Volatile Comb.....	30.11	32.57	18.76	16.55	32.00	35.27	35.29
Fixed Carbon.....	55.79	57.87	73.15	76.94	49.50	52.79	53.05
Ash.....	{ 8.31	{ 8.07	{ 7.65	{ 5.95	{ 13.68	{ 6.52	{ 10.21
(Lower figures, in dry coal.)	{ 8.82*	{ 8.19*	{ 7.69*	{ 5.99*	{ 14.88*	{ 6.90*	{ 10.36*
Sum.....	100.000	100.000	100.000	100.000	100.000	100.000	100.000
Total S.....	1.03	1.13	1.02	0.81	4.48	2.09	3.42
S. in ash.....	0.13	0.02	0.11	0.12	0.22	0.14	0.03
Volatile S.....	{ 0.90	1.01	0.91	0.69	{ 4.26	{ 1.95	{ 3.39
	{ 0.96*				{ 4.43	{ 2.06	{ 3.44
C.....*	71.81	75.57	80.17	82.85	63.21	74.63	72.28
H.....*	4.85	5.13	5.08	4.77	4.67	4.96	5.05
H-½ O.....*	3.41	4.04	4.49	4.22	3.12	3.71	4.19
N.....*	2.04	1.40	1.46	1.32	1.15	1.43	1.42
O.....*	11.52	8.70	4.69	4.38	12.16	10.02	6.85
146 C.....	10,490	11,020	11,700	12,180	9,240	10,890	10,630
620 (H - ½ O).....	2,104	2,506	2,778	2,620	1,928	2,296	2,598
40 S.....	.085	.040	.036	.028	.255	.082	.138
Heating Power, } Wet... } Dry... Cal. Dulong†.....	12,120 12,885 — 255	13,680 13,667 — 302	14,490 14,572 — 43	14,780 14,880 — 132	11,100 11,674 — 261	12,420 13,151 + 116	13,310 13,404 78
Combustible.....	85.90	90.44	91.91	93.49	81.50	88.06	88.35

* Ultimate analyses and calorimetric results are referred to dry coals.

† By A. C. Lane.

TABLE D.—ANALYSES BY C. H. HILTON.

Number.....	1	2	3	4	5	6	7	8	9	10	11
Location.....	No. 1, Pere Marquette.	Standard.	No. 1, Somers.	Owosso Co.	Lower Verne.	Verne.	Sebewaing.	Michigan Co.	Grand Ledge.	Pinconning.	Ride River Channel.
Ash.....	3.30	2.26	5.65	3.52	9.15	10.10	8.83	15.15	10.14	12.23	9.33
Total S.....	1.10	0.91	1.01	1.11	3.02	4.76	5.80	6.92	4.61	1.04	7.00
S. in ash.....	0.10	0.03	0.19	0.02	0.03	0.10	0.05	0.25	0.04	0.03	0.43
Volatile S*.....	1.00	0.88	0.82	1.09	3.59	4.66	5.75	6.67	4.57	1.01	6.57
S. from Fet.....	1.028	0.881	0.835	1.085	4.105	4.366	6.52	6.64	5.223	1.074	6.41
Iron.....	0.90	0.77	0.73	0.95	3.51	3.82	5.71	5.81	4.57	0.94	5.61
Volatile Matter.....	41.25	41.36	39.44	39.63	41.24	42.11	41.39	40.08	38.43	38.59	37.79
Heating Power.....			13, 167								

* By subtraction.

† By computation as eight sevenths of the iron, compare p. 52.

TABLE E.—ANALYSES BY A. N. CLARK.

Number.....	1	2	3
Location.....	No. 1, Pere Mar- quette.	New Hope, Jackson.	Grand Ledge.
Moisture.....	10.40	5.20	7.00
Volatile Comb.....	32.40	45.65	39.10
Fixed Carbon.....	55.20	45.65	46.40
Ash.....	2.00	3.50	7.50
Sum.....	100.000	100.000	100.000
Total S.....	1.45	3.39	3.42
Fe ₂ O ₃ + Al ₂ O ₃	tr.	2.24	5.32

TABLE F.—PROXIMATE ANALYSES.

Number.....	1	2	3	4	5	6	7	8
Location.....	Sebe- waing.	Cor- unna.	Sagi- naw.	Flush- ing.	Cor- unna.	Sebe- waing.	Jack- son Can- nel.	No. 2, Pere Mar- quette.
Moisture.....	4.82	3.03	.....	10.425	3.968	4.46	2.00	1.98
Volatile Comb.....	44.58	38.78	31.39	29.70	39.476	47.92	49.00	43.49
Fixed Carbon.....	41.52	43.44	63.78	53.365	46.319	40.45	45.00	53.20
Ash.....	5.70	11.17	3.79	6.575	8.549	4.04	2.00	.97
Total S.....	3.38	3.57	1.04	.935	2.688	.305	2.00	.394
Sum.....	100.000	100.000	100.000	100.000	100.000	100.000	100.000	100.000?
Total Combustible.....	89.48	85.79	95.21	83.00	87.483	91.42	96.00	97.084
Volatile ".....	46.27	40.57	31.91	30.17	40.820	49.44	50.00	43.69
Fixed ".....	43.27	45.23	64.30	52.835	46.663	41.97	46.00	53.40
Ratio of fixed to total comb..	.493	.527	.668	.636	.534	.458	.477	.55

TABLE G.—PARTIAL AND PROXIMATE ANALYSES.

Number.....	1	2	3	4	5	6	7	8
Location.....	Munger.	Scotts, Kalamazoo Co.	Cor- unna.	Rifle River Cannel.	Rifle River, Lower.	Jack- son.	Alpena.	Kniffin, Clinton Co.
Moisture.....	{ 59.30 }	1.99	6.23	11.35	3.60	44.	{ 17.96 }	0.36
Volatile Comb.....	32.22	40.08	35.46	35.80	40.00	.....	6.49	32.92
Fixed Carbon.....	8.58	44.89	45.45	41.10	55.40	.....	75.55	28.76
Ash.....	.....	13.29	12.04	11.87	1.00	.....	.....	42.96
Sum.....	100.000	100.20	99.28	100.000	100.000	100.000	100.000	100.000
S*.....	.....	.....	.....	5.84	.....	.....	.....	7.68
Ratio of fixed carbon to total combustible. ...	.....	.528	.561	.535	.57	.....	.....	.....

* In this and the following tables where no sulphur is reported, it was undetermined.

TABLE H.—ANALYSES BY BRADLEY* & REED.

Number.....	1	2	3	4	5	6	7	8	9	10	11
Location.....	St. Charles.	Standard.	Valley, Bay City.	New Hope, Jackson.	Trumbull, Jackson.	Wenona, Bay City.	Pere Mar- quette, Reed.	Pere Mar- quette, Bradley.	Sebe- wauing.	Mich. Coal Mining Co., West Bay City.	Mich. Coal Mining Co., West Bay City.
Sp. Gr.....	1.216	1.19	.....	1.2315	1.23	1.232	.....	.....	.....	.....	.....
Moisture.....	7.55	5.54	1.7	5.53	3.04	2.06	6.33	5.903	1.453	1.46	1.850
Volatile Comb	37.56	33.077	35.25	44.63	39.80	41.4	33.90	34.632	36.429	36.18	34.117
Fixed Carbon.....	54.08	59.23	53.55	44.97	.....	51.39	57.88	57.375	50.384	54.17	56.633
Ash.....	.97	2.1	9.5	5.	.....	4.05	1.89	1.998	11.704	9.17	7.400
Sum.....	100.000	100.000	100.000	100.000	100.000	100.000	100.000	100.000	100.000	100.000	100.000
Total S.....	2.1-6	2.01-3	undet.	2.01-6	.....	* 2.04-9	.....	.....	.....	.....	.....
Ratio of fixed carbon to com- bustible.....	.59	.642	.613	.502	.....	.556	.631	.624	.581	.600	.60

* Some of these analyses prepared for a thesis for the degree of M. A. at Alma College.

TABLE I.—RECENT ANALYSES (MAINLY TESTED CALORIMETRICALLY).

Number.....	1	2	3	4	5	6	7	8	9	10	11	12
Location.....	Sag- naw coal	"Slack."	*Sag- naw.	Sag- naw.	Sag- naw.	Sag- naw.	Sag- naw.	Sag- naw.	Robt. Gage Coal Co., St. Charles No. 4.	Robt. Gage Coal Co., St. Charles Lump.	Bone coal	St. Charles Coal Co., Upper coal
Moisture.....	7.60	.875	12.39	12.51	.....	.....	.....	.....	1.72	2.37	8.06	4.84
Volatile Comb.....	37.895	38.765	30.47	30.38	34.78	34.61	35.27	35.21	33.74	36.18	30.74	40.13
Fixed Carbon.....	50.73	48.80	55.92	55.89	63.83	63.99	64.73	64.79	57.29	58.99	49.29	51.49
Ash.....	3.77	11.56	1.22	1.22	1.39	1.40	.....	.....	7.25	2.46	11.89	3.54
Sum.....	99.995	100.000	100.000	100.000	100.000	100.000	100.000	100.000	100.000	100.000	100.000	100.000
Total S.....	.99	2.32	.....	.....	.....	.....	.....	.....	.....	.....	.885	2.22
Total combustible.....	88.625	87.555	86.39	86.27	98.61	98.60	100.	100.	91.03	95.17	80.03	91.62
Ratio of fixed carbon.....	.573	.558	.646	.647	.....	.....	.....	.....	.623	.619	.615	.568
Obs. Calorimet.....	12,531	.....	11,692	11,663	13,345	13,331	13,522	13,519	+12,508	+13,438	.....	.....
Calculated from analysis.....	.....	.....	12,600	.....	.....	.....	.....	.....	13,290	13,900	.....	.....

* Moisture part of the coal, not superficial, burned up rapidly, soon exhausted. Sample taken by T. Pray, Jr., Dec. 1899, Mahler and Carpenter calorimeters used.
 + 27.098 to 27.736 grams of lead reduced per gram coal.
 † 27.38 to 27.34 grams of lead reduced per gram coal.

TABLE J.—SUPPLEMENTARY ANALYSES.

Number.....	1	2	3	4	5	6	7	8	9
Location	Goetz No. 3.	Mas- sillon No. 1.	Michi- gan Mine.	Old Moni- tor.	G. Coal No. 1.	G. Coal No. 2.	Flush- ing No. 1.	Flush- ing No. 2.	Flush- ing No. 3.
Moisture.....	5.44	2.68	9.57	10.08	3.76	6.50	2.91	2.94	2.37
Volatile Comb.....	37.71	46.68	40.93	36.26	37.05	33.98	40.60	40.73	40.68
Fixed Carbon.....	48.43	40.93	46.18	49.94	50.10	40.60	54.35	54.06	50.82
Ash.....	8.42	9.71	4.35	4.67	9.09	18.92	2.14	2.27	6.13
Sum.....	100.000	100.000	100.000	100.000	100.000	100.000	100.000	100.000	100.000
Total S.....	.59	3.08	.98	1.12	3.72	1.79	1.12	1.58	3.14
Total combustible.....	96.14	87.61	87.06	88.30	87.15	84.58	94.95	94.79	91.50
Ratio of fixed carbon to it.....	.557	.467	.530	.585	.575	.474	.573	.570	.556

In "Mining and Metallurgy for Oct. 1, 1901, p. 565, we find in regard to calorimetric tests that Dr. Langbein, of Nieder Lössnitz, has constructed a new apparatus for that purpose. He publishes 150 complete chemical and calorimetric experiments of heating materials, and 153 purely calorimetric experiments, which he has carried out as a supplement to his experiments, in evaporation. The accompanying table is the result of his experiments.—British Foreign Office Reports, Annual Series, No 2,671.

	Calorimetric Units	
	From	To
Sawdust briquettes	3,400	4,100
Peat	2,700	4,800
Lignite	1,900	3,100
Briquettes	4,800	5,400
Bohemian brown coal.....	3,600	5,500
Coal from Silesia	5,300	7,500
" Saxony	5,400	7,200
" Saar district	5,800	7,700
" Westphalia	6,600	7,900
" Great Britain	6,000	7,800
Coal briquettes	6,100	7,700
Anthracite	7,600	8,100
Crude coke	3,500	4,000
Coal coke	5,600	7,400
paraffin oil	9,800	9,840
Petroleum	10,300	10,330

These tests may be compared with Table II.

§ 17. Conclusions.

Summing up the analytical tests and results of this chapter we may come to the following conclusions: There are but three seams, of the seven or eight existing, which have yet been worked enough to give us some idea of their character. They are all bituminous coals, rather high in moisture and inclined to be gas coals, and to pass into low grade cannel coal.

The uppermost of these three seams, the Upper Verne or Monitor seam, is the only one which appears to be at all gassy. It is a coking coal, duller than the next lower seam, and containing more charcoal, and a medium amount of sulphur. The roof is a Lingula shale. The ratio of fixed carbon in combustible runs up to .57.

The next seam, the Lower Verne, is generally not far below, often near enough to be mined with it; it is also a coking coal, but is high in sulphur and ash. The roof is frequently fossiliferous and calcareous. The ratio of fixed carbon is lower, often less than .50.

The third seam, the Saginaw seam, is higher in moisture and fixed carbon than the previous seams, but contains much less ash and sulphur, in fact, very small quantities, but is not what is ordinarily classed as a coking coal. It is a good heating coal, but rather quick. The temperature of the chimney gases should be kept low, to avoid loss of heat in the evaporation of the moisture contained. For the Saginaw seam the best analyses give a ratio of fixed carbon to total combustible of 0.61, while in the Verne coals this ratio is usually near 0.50, but is more variable.

None of the coals as yet appear to be very well adapted for the burning of Portland cement, which is said to require a coal that is at the same time rich in volatile combustible and poor in sulphur. The cream of the Upper Verne coal, compare J1 and J3, meets most nearly these requirements.



THE FLAT SAGINAW VALLEY. VIEW SOUTH FROM DUMP OF SAGINAW MINE.

CHAPTER V.

THE EROSION AND DISTURBANCE OF COAL.

§ 1. Recent channels.

After the formation of the coal beds, they have been cut into and partly carried away, not only by the now open channels of the present rivers, but also by channels which are now filled with unconsolidated materials, gravel, sand, till, etc., and by still earlier channels which are filled with rocks, usually sandstone.

We have then to discuss three kinds of channels, open channels, gravel channels or "washouts," and sandstone channels.

Open channels or valleys exposing the coal on their sides are neither numerous or deep, and this fact is one reason why the coal basin has been so tardy in development.*

Beginning on the east of Saginaw Bay and going around the basin with the hands of a clock, in describing such channels, we find that on Coats Creek, near Tuscola, coal is said to have been used many years ago from exposures in the bank, and sandstones occur in the bed of Cass River a short way above town. The Flint River near Flushing (Sec. 4 and Sec. 22), and the Shiawassee from above Corunna, at intervals down to Saginaw county, show exposures of coal measures. The Cedar and Grand Rivers show exposures at intervals from Williamston to six miles below Grand Ledge, and Grand River and the adjacent streams around Dimondale, Eaton Rapids, Chelsea and Jackson, expose some glimpses of the coal measures. There is a glimpse or two of coal measure sandstones at Ionia and as far northwest as Kent county, but thence there are no bedrock exposures until we get clear around to the Rife River in Arenac county at Omer and above. The center of the coal basin is heavily covered with drift.

Except in the comparatively small mines of Grand Ledge, the valleys are in no case so deep that coal exposed on the side of

*R. R. Lansing. Exposition of the mineral coal of Michigan, pamphlet, Detroit, 1864; describing the earlier known exposures, especially those on Cedar River.

them can be effectively worked. It follows that there are no important self-draining coal mines. The States to the south, on the other hand, like Ohio, have deeper river valleys, and the coal was extensively exposed on the sides of the hill, where it could be worked cheaply and easily.

§ 2. Drift filled channels.

The States farther south have been somewhat covered with drift, but Michigan has been doubly plastered over; first rough coated with till and gravels washed directly from the great ice sheet which overspread it not so long ago from the northeast; then given a finishing coat up to nearly 200 feet above the present lake level by the deposits of the Great Lake system when the water was dammed up by the great ice sheet to the north, so that it flowed from a lake in the Saginaw valley across the peninsula to Lake Michigan, then ultimately to the Mississippi.

The smoothness of the resulting topography is well illustrated by the view from the top of the dump of the Saginaw coal mine, Plate V.

Before the period of the ice sheet, the land surface stood higher, and steep channels 100 to 150 feet deep and more were carved in coal measures. The cross-section of the Woodville mine, Fig. 4, reveals very clearly such a channel, which would have exposed the coal nicely before the glacial time.

Numerous other channels have been revealed by boring. One channel which skirts the east side of the Bayport limestone in Huron county is fully described in the report on that county.*

Leaving the county near its southwest corner it passes close to Unionville in Tuscola county, then flows west, crosses into Bay county, is well marked in Portsmouth and going south through Frankenlust township, probably enters Saginaw county in Kochville or Zilwaukee townships, thence goes southwest as far as Paines, receiving a tributary from South Saginaw. Then it passes west towards Alma, receiving a branch from Auburn and Midland, where the depth of drift varies from less than 200' to 300' or more.

The general course of some of the main channels is indicated by the bends of the rock contours of Plate I, but there must be many smaller tributaries not as yet located.

If this mantle of drift were stripped off it would be as easy to find the coal as in southern Ohio or Kentucky. As it is now, a

*Part II of Vol. VII of these reports.

great element of uncertainty in the development and estimate of the amount of coal in a given tract is added. The closer the coal is found to the rock surface in preliminary boring, the more likely of course it is that one of these channels may be found cutting down to or through the coal. The Woodville section indicates, what is probably the fact, that they are often narrow and steep walled. Probably the general form of the rock surface is pretty flat and gently sloping to the middle of the basin, but engraved with steep-sided valleys.

It has been recently suggested in *Mines and Minerals** that coal is likely to rise toward its outcrops, especially when underlain by fire-clay, and the cause suggested is the weathering and swelling of the beds when exposed to the weather.

This suggested principle holds true at Grand Ledge and a number of other points in other states which I have visited, and beside the reasons given for it in *Mines and Minerals* it may be due to the fact that erosion proceeds most rapidly along faults and anticlinals.

The figure of the section at the Woodville shaft, p. 33, indicates a similar relation of the coal to the old drift-filled channels, and similar relationships may be observed in the Pere Marquette No. 1 shaft and in Bay county. It seems, therefore, as though we might accept the following practical rule as of some value:

Toward an outcrop or washout, the coal is likely to rise.

§ 3. Sandstone channels.

Besides the channels just mentioned we find others which have cut out the coal and are filled with compact sandstone.† These do not weaken the roof as do the former, but both classes make much trouble by letting in water. For instance, the mine of the St. Charles Coal Co. is so close under a heavy sandstone, that it is quite wet.

These channels indicate that before the time of the ice sheet, in fact, probably soon after the coal was formed, stream channels were cut into the coal measures and then filled up again with sandstone formed from the deposits. In Holcroft's plan of part of the Porter coal mine (p. 48) and in some other cases we can see clearly from the shape of the cross section that the sandstone channel really came down from above and cut out the coal.

*By Charles Catlett, January, 1901; also *Am. Inst. Min. Eng.*

†Keyes, Iowa, 1894, pp. 181-186.

Keyes* in one of his figures shows a sandstone cutting out the coal very much in the same shape as at the Porter mine. The erosion is also indicated at the Porter mine by the fragments of coal in the sandstone. Numerous records of borings seem to show where such sandstones appear in a series of records and replace the coal, but mere borings may be ambiguous. For when, as in the old East Saginaw well, we find 78 feet of sandstone replacing the shales and coal that occur in the O'Donnell Spencer well and the Saginaw coal mine not three miles off, while at these latter points there is a well marked sandrock 34 feet thick or so just beneath the coals, it is not at all certain whether the East Saginaw sandstone is such a channel as we have been describing or whether the coal and shale series was not, as I am more inclined to think, laid down unconformably in a hollow in the sandstone, just as we find swamps between the sand ridges of the present lake shore. We have to search for reliable indications as to whether the sandstone which cuts out the coal connects with the beds above or below it. In the particular case of the Saginaw and Pere Marquette No. 1 mines, a careful study of numerous records convinces me that the coal rises up and laps upon and into the sandstone which occurs to the north and east for the first 50 feet or so below the surface, and that the coal was formed as a pocket or swamp in that formation against a sand ridge. Probable indications of real sandstone channels are also frequent, as when Mr. Liken near Sebewaing, put down a well for water,† and found three feet of coal 36 feet from a previous boring which at the same level was in the midst of over 20 feet of sandstone.

I think that where the want is produced by a sandstone cutting down from above it is likely to be less extensive than otherwise.

The rock channels besides being described by Keyes as cited, are well described by Stevenson in Pennsylvania, who is really pioneer in detailed description of bituminous coal sections.

§ 4. Faults or displacements.

Coal beds are liable to be disturbed or interrupted and deteriorated, e. g., by the following features:

(a) Faults, i. e., displacements which are almost always "normal," i. e., the surfaces of displacement slope toward the

*Loc. cit. Fig. 20.

†Vol. VII of these reports, Part II, p. 149.

side on which the coal dropped, so that the coal may be imagined to have slid down. See the figure of the fault at Sebewaing (Fig. 3, p. 31). This is likely to be the side of the thicker coal. The fault lines are frequently occupied by—

(b) Clay seams or veins (perhaps occupying the fissures made by the faults) which traverse the coal.

(c) "Sulphur partings," that is, veins or seams charged with sulphide of iron.

(d) "Spar seams," that is, veins or seams filled with some white material, generally either calcite, which effervesces in vinegar, or gypsum, which does not.

There are other phenomena which are sometimes called faults, for almost anything which prevents the miner from finding the coal where he expects it, he is liable to consider and call a fault, including not only displacements such as we have mentioned, but rolls, horsebacks, sandstone bars and channels.

In such a broad sense it would be better to use a term like "want" or "trouble." The geologist, however, limits the use of the term faults, and applies it only to those cracks in the earth's surface by which the coal has been displaced and the beds above and below as well. In the Jackson coal mines we have such displacements and there is one well developed in the mine of the Sebewaing Coal Co. (Fig. 3). Here the coal rises more sharply as we approach the fault, and this is often the case. The motion and slipping along the fault place has polished off smoothly shining surfaces in the coal and slates, sometimes as bright as jet, which are called slickensides.

Along the fault line, which has a dip of about 65° , there are open holes, apparently water channels, which appear to have been dissolved out by underground waters working along the cracks and dissolving the pyrite.

The actual throw at the fault is but two feet or so. The Iowa faults are described by Keyes as follows: Seldom with more than a few feet throw, the majority normal, with a grade 15° to 45° from vertical, the two faces of the rubbed fracture very dense and highly polished. Frequently there are a number of faults parallel to each other. In some instances, in passing from a hard to a soft medium the line of fracture is bent away from a normal to the contact plane like a ray of light, passing out of water. Reversed

or thrust faults, Gresley's* "Slack" or "soot" veins are little known in Michigan, but there are said to be a few around Jackson.

§ 5. Veins.

(a) Clay-filled veins, "clay seams," "mud seams."

The phenomena known by above names have been quite fully described and figured by W. S. Gresley,† and but little is known of them in Michigan, so that we need not dwell on them here. In the majority of cases, perhaps, they are fillings of shrinkage cracks, and one may be described in a general way as a more or less vertical, crooked, tortuous, often branching, ragged-sided wall or dike intersecting a seam of coal, composed of compact indurated clayey materials or a mixed debris of rocks forming a breccia or conglomerate mass, varying in width from a mere streak or film of clay to as much as 15 feet, but averaging about 10 inches. It may have any direction, may extend a few yards only or run a mile or more before being lost to sight. It may branch and even reunite vertically and horizontally, and the adjacent coal may be toughened, twisted, and spoiled or displaced. In this latter case the clay vein probably occupies the fissure of a fault. It "may form part of a network of veins and may extend indefinitely above and below the coals." Though Gresley says that the direction of the clay veins is irrespective of other structural features of the coal, some of his figures (6, 7, and 16) suggest that those which he figures are divided into two systems, which, though more or less irregular, are at an angle to each other which is bisected by the cleat of the coal, as torsion cracks of a substance twisted under pressure are bisected by the direction of pressure. These figures would then indicate that in such cases the cracks were opened by a twisting of the coal seams, while under such a pressure that clay was forced into the cracks, and a "cleat" produced.

Other figures given by Gresley indicate that in the cases they represent the clay seams figured were due to the shrinkage of the coal, under a pressure that forced the clay into the cracks as they opened.

(b) Spar veins are more likely to be smooth coated, following the cleat or joint planes of the coal. They are generally white, in strong contrast to the dark coal, and are usually not over a fraction of an inch thick.

*Bull. Geol. Soc. Am., 1898, Vol. IX, p. 47.

†Bull. Geol. Soc. Am., 1898, Vol. IX, pp. 35-38.

(c) "Sulphur partings."

These are pyritic streaks, i. e., streaks of sulphide of iron, either in the shape of pyrite or the similar but more easily decomposable mineral marcasite. When they cross the coal nearly vertically they are probably veins following faults, but they also occur in streaks parallel to the bedding. While in some cases they correspond to the faults, in other cases no disturbance is noted. Holcroft's plans of the Jackson coal district show them abundantly.

The "sulphur" was once sold for 5 cents more per ton than the coal to an acid and fertilizer factory at Jackson, and one of the open fields is the economic utilization of the waste pyrite of the Lower Verne seam around Bay City.

In connection with the waste bitterns for potash, and the slaughter-house refuse for phosphorus, I imagine a successful fertilizer business could be built up.

It might also be used for cheap large scale disinfection.

§ 6. Horsebacks or bars.

Keyes* gives a figure of a horseback in the sense of a ridge rising from beneath the coal, that is from the footwall, which is remarkably sharp. He defines a "roll" as a place where the roof occupies a portion of the seam. It may be a mere indentation or nearly replace it, i. e., be a "pinch," and may occur in connection with a clay seam or fracture, which fact he also mentions.†

On the other hand, Stevenson‡ calls "horsebacks" what Keyes calls "rolls" and we have called "channels," coming down from the roof and cutting out a greater or less thickness of clay, while rolls he defines as swells of the under clay. It will be observed that Keyes and Stevenson are diametrically opposites in their definition. They may both conform to local usage, but miners are not scientifically precise in their use of language and steer clear of barren spots, no matter by what names they are called, so that in very many cases we are not certain of the nature of the intercepting beds. For instance, between the Standard mine on Section 6, Bridgeport township, south of Saginaw, and the Pere Marquette No. 1 and Saginaw mines coal basin, there is an area where the coal seam of those mines does not appear, being said to be cut out by a big sandstone, which is said to come in from the roof. It is really not certain, however, whether it is a channel or a bar; my

*Iowa, 1894, p. 206.

†Iowa, 1894, pp. 189-266.

‡Penn., KKK, p. 296.

own impression is that it is a bar, as there is a rapid rise to the south approaching it in the mine, running up to 5° or 6°.

It seems certainly more natural to speak of a rising up of the foot-wall as a horseback. When we can be certain which we have, it will be better to avoid ambiguity and speak of channels and bars, and otherwise to speak generally of "wants," a miner's term for places where the coal is wanting.

We may picture the formation of bars as follows: Suppose the shore of Saginaw Bay to be depressed and buried, and covered with later deposits. The swamps behind the sand ridges would in course of time become thin coal seams, and the sand dune ridges and oak islands would become sandstone bars and horsebacks.

Other bars might be due to uneven pressure and settling with faulting. If clearly made out we should call them fault blocks rather than bars.

CHAPTER VI.

THE DEVELOPMENT OF COAL.

§ 1. Peculiarities of occurrence as affecting development.

There are some peculiarities in the occurrence of coal in Lower Michigan which have retarded and will affect its future development.

As we have said, practically all the coal lies below water level, and mainly in artesian well country. Ample provision must therefore be made for economical pumping. Care must be taken to steer clear of porous beds and fissures, and artesian wells. The water from an artesian well whose casing burst was a considerable annoyance to the Sebewaing Coal Company. The water has flooded their mine since this report was first written. For the same reasons slopes or inclines leading down to the coal will probably not be advantageous, as the water will find its way in too much, and though they have been tried at Jackson, Elk, Williams-ton and Corunna, have not been successful. The amount of water to be handled has* been a great source of annoyance and failure, and it is important that the shafts for pumping should be put down in the lowest parts of the coal, so that the water may run to the pumps. This requires careful preliminary testing, and the test holes should be plugged, lest they aid the circulation of water and make necessary more pumping.

The presence of numerous deep drift channels also makes the work of development uncertain. They are to be carefully avoided, since near them the roof is likely to be treacherous, and often the weakness of the roof prevents success. Thus the true value and best method of working an area of coal lands cannot be determined without an expensive series of preliminary borings.

The strata are quite a little disturbed and uneven, and though Lawton† is somewhat within the truth in saying that there is but

*Lawton, 1881, p. 24.

†Lawton, 1886, p. 173, and other places.

one workable seam, "never over four feet deep," and averaging $2\frac{1}{2}$ to 3, it is true that the beds are prevailingly thin.

On the other hand, fire-damp and coal dust explosions are almost unknown, and other noxious gases are not troublesome.

§ 2. Principles to guide explorations.

Summing the results of our inquiry, we may lay down with some caution the following practical principles, which should be compared with those laid down by Winchell:*

(1). A good place to begin preliminary explorations is a belt a few miles (five to fifteen) within the limits of the coal basin as marked on Plate I. Nearer the center some of the coal beds are liable to have run out (though there may be higher later formed ones of which we have no knowledge), and the drift and depth to coal is greater. Nearer the margin the coal is more likely to be cut out by some channel and the base of the coal series is soon reached, but—

(2). A coal bed once located, though not thick enough to work, may often thicken, especially in that direction parallel to the margin of the basin, in which it grows deeper, so that it may be followed by borings to where it will be worth working.

(3). Generally speaking, the coal will rise toward the margin, except for minor undulations. But shafts should not be located until the property is so proved up by borings that they may be located at the lowest point of the coal.

(4). Hitherto almost all the work has been done on the south-east side of the basin. A line from Sebewaing to Jackson, and one from the Wolverine Mine, near Bay City, toward Grand Ledge, would be very nearly parallel, and would include practically every mine in the state that has produced coal in commercial quantity. The little that has been done at Standish, and around the Rifle River, at Hubbard, Pinconning and Rhodes, has not been more than sufficient to show that coal exists there. Montcalm county and the valley of the upper Muskegon are promising regions entirely undeveloped, for the rumors of coal found there seem to refer entirely to coal in the drift.

(5). Over most of the coal basin there is an extra heavy coating of unconsolidated materials (drift), and probably the coal measures have suffered heavy erosion. Hence exploring for coal alone

*1861 report, p. 157.

will be too expensive to pay, until we have more definite knowledge than at present, so that it is very important that careful records be kept and preserved of borings for all other purposes, e. g., artesian water and brominiferous brines, which are likely to occur in this region.

This is especially true of the northwest region, where the surface drift is apparently over 300 feet deep.

§ 3. Methods of testing and developing.

We pass next to consider methods of explorations and testing. The one that might be thought of first, viz., sinking a shaft, is the last to be used, and in fact need not often be resorted to, until it is time to begin mining. The first method suggested is that of digging wells or test pits, as they are called in the iron country. As a general thing, however, any coal reached by shallow pits will not be conveniently workable—the coal will dip away from the shaft and be wet, and very likely have a poor roof.

The methods of exploring suited to the iron or copper country, or to putting down wells in unconsolidated deposits, are of no use save in exceptional circumstances. When previous explorations have made it probable that only soft shales in the way of rock overlie the coal, and when the overlying drift is not very thick and very bouldery, dug wells may be used. Bored wells (in clay) and driven wells (in sand) will find their main utility in tracing out cheaply the form of the surface of the bed rock where there is danger of gravel channels. When there is a probability of encountering an embarrassing quicksand it may often be a good thing to use the scouring process (by which a strong stream of water washes out the sand ahead of the casing as it is tapped down) until the casing is extended to bed rock, after which it will be easy to begin drilling.

The main reliance is upon drilled wells, and we may divide drills into two classes, churn drills, with an up and down motion (percussion drills), and rotary drills.

Churn Drills.—The churn drills are the kind commonly used by drillers in putting down artesian wells for farmers, saline wells, etc., and are usually the first thing at hand and in many cases the cheapest. Most incidental explorations will have been done with them, and the records are well worth keeping. Their chief disadvantage is that the drillings from a churn drill (which is worked by dropping the tools down frequently upon the rock while they

are slowly rotated) come up as fine as powder or meal, with the parts from different layers more or less mixed, so that it is difficult to determine the exact qualities of the rock, and exceedingly easy to confound with the coal more or less of the black shale roof that almost invariably comes above it. By reaming out a small hole to somewhat larger size, somewhat coarser samples may be obtained, and I am informed by those experienced, that they can recognize with their hand on the cable the peculiar crunch of the coal under the drill, owing to its greater brittleness, when it is struck, and by then turning the drill exactly 90° between each stroke, and "quartering" the coal, they can get larger fragments. So that if they also hoist and bale out with the sand pump at every few inches on passing coal, or use so called "jetting" tools which wash out the meal continuously, they can get a very fair idea of the coal. But there is a great weight of responsibility both on the skill and on the integrity of the driller.

There are two styles of churn drill, according as a cable is used to lower the tools or a series of poles. The former gives rather cleaner samples, for the poles tend to knock off more pieces of the rock along the way down. But the poles have the great advantage that on nearing the coal, they can be changed from a churn drill into a rotary drill.

The cost of putting down a single two-inch hole for a farmer's well two hundred feet or so, around Saginaw, has got down to 50 cents a foot or so of late. It used to be considerably more, and the real cost varies greatly according to the particular difficulties encountered. A driller must allow a good margin for contracts on the first few holes in a new district. Limestone or pyrite take very much more time than sandstone or shale, and accidents of one sort or another seem to take half the time of drilling a well. The cost to a company owning their own machine and putting in many holes where the formation is well known, I understand may be not over 25 cents to 35 cents a foot.

Rotary Drills.—The simplest form of rotary drill is probably the crown drill—a length of gas pipe, with notches like saw teeth filed in the cutting end, or a tempered steel drill of the same shape. In sandstone explorations nice cores have been taken out 3 to 4 inches in diameter by a chilled steel drill, at a lower cost for fifty feet or so than the churn drill. In this form ordinary gas pipe is rotated, while beneath it have been dropped angular frag-

ments of an especially hardened steel or "adamant." Practically it is a method of grinding one's way down. Mr. Etzold's explorations for the Michigan Coal and Mining Co. were largely by this method.

As coal is very brittle large cores must be taken if it is expected to get them up whole.

The diamond drill has the edge of the round bit armed with black diamonds, known as carbons or bort, set alternately on the inner and outer side. These drills are at present very expensive (\$1,000 to \$2,000). It has been but little used, the 907 foot hole at Corunna* being the chief instance. Mr. N. P. Bradley also put down a hole near Bay City, described p. 170. The diamond drill is most effective in a hard and uniform rock, like hard pyritic sandstone, and is especially to be recommended for very hard rock, but is not to be recommended when the rock is soft and sticky, or especially when of very irregular hardness, breaking away in angular bits that jam, like some conglomerates and cherty limestones. Cores $1\frac{1}{2}$ inch in diameter cost somewhere about \$1.00 a foot. In sandstone and shale the cost has been as low as 44 cents a foot, and progress as rapid as 30 feet a day.† The relatively least expensive depth is, when the diamond drill is used, about 600 feet.

In all rotary drills the drill is forced into and against the rock, and the hole is more likely to be crooked than where the drill is dropped.

It is obvious that no one form of drill that we have mentioned has all the advantages under all circumstances, and the subject is so far out of the line of our main purpose that the remarks alone serve merely to remind one of the expense and desirability of exploration,‡ the advantage which a man educated to the business has in choosing the method best adapted to the circumstances, and finally to suggest to driller, land owner or explorer a wider range of investigation and choice of that which will serve his need than might otherwise occur to him.

If it is merely a question of following the coal into the valley or "swamp," or of determining the amount of roof and presence of channels, a churn drill in an experienced and reliable hand should suffice. If the quality of the coal or adjacent beds is in question,

*Vol. V, of these reports, Plate XII; also Lawton, 1886, p. 176.

†See *Mines and Minerals*, Jan., 1900, also Vol. VI, Part I, of these reports.

‡See *The Michigan Miner*, No. 2, Jan. 1899, p. 10.

a crown drill or a drill that will give a three or four inch core at least should be employed, and I should recommend taking at least one core before sinking a shaft.

Sinking Shafts.—So far as concerns sinking shafts, we must refer to any treatise on mining, as it is too large a subject to try to summarize. We need only add that in the district under consideration workmen have often encountered dangerous flows of water in putting down wells, so that preparations must be made to fight water and timber closely. In putting down shafts against water it has often been found advantageous to put down two shafts together not far apart, running first one and then the other ahead a few feet, and pumping vigorously in the other one. There is no loss in this in coal mining, for two shafts are needed for ventilation and safety anyway.

§ 4. Incidental development and information.

It is obvious from what has been said that the heavy expense of the necessary preliminary explorations prevents the development of many coal bodies, which once located could be worked at a profit, and many of the borings for water and brine would, if properly watched and recorded, give valuable information as to the presence of coal. But the following conversation is typical:

"Say, don't you remember that you brought in some coal to me when you put down that last salt well for me some years ago?"

"Yes, and you said, 'What are you giving us?' and suggested that I had dropped it down."

"Well, do you remember how far down it was and how thick?"

"No, I can't say now, but my machine is right near here, and we can run her down and see very easy any time you like."

Some of the better well drillers keep a careful record of all their holes for whatever purpose, but no record is as good as a set of samples, for there may arise some entirely unforeseen questions as to a particular quality of a fire-clay, of the presence of clays, iron ore, or zinc ore, which no one thinks of now (any more than the saw mill owner, hard pressed to get rid of his slabs, used to care for a small bed of steam coal), but which may later be of practical value. If records, and especially if accurate tubes of samples such as adorns the corridor of the Alma Sanitarium, had been kept of all the wells which have been put down, it would be possible to save thousands of dollars in fruitless explorations, by guiding explorations in future, so that the right spots for shafts may be

sooner found. Not only this, but there would be a fund of information concerning many other raw materials destined to become of economic value.

Beside borings there are other sources of information so indirect and technical in their character as to belong to the professional geologists. The presence of coal in surface deposits, if in the till, indicates coal to the north-northeast and not directly beneath, but if abundant and coarse, not far off, if in river sands in the rock or till up-stream. Again, the well waters are often more highly sulphated in the Coal Measures.

Role of the Geological Survey.—Now the part of the State Survey is to put together, and aid and guide the collection and preservation of this information. Two and two of knowledge together often make more than four. A well that shows no coal may show some bed recognizable in other wells that do contain coal, by which we may infer that it has not gone far enough and the coal is still beneath, or perhaps that it is cut out by a channel, and may so guide us in farther search. If one studies the reports of great mining States like Pennsylvania, where the publications of the Geological Survey run into the hundred, he will find that a vast amount of the data is furnished by private exploration. The natural exposures in our coal basin are very much fewer, and it is to be presumed that my predecessors have largely made what can be made from them. And yet there is a great deal more to be known about the geology and natural resources of the Saginaw Valley, and each year many wells are sunk which would throw light. The State Survey cannot undertake the work of the private explorer, in finding out the value of the land of a particular private individual. But the State may play the part of a vast co-operative society, and if it can guide him in putting in his work and money to best advantage, and in return receive information which is of no exclusive advantage to himself, possibly of no immediate practical value to anybody, which will in due time enable the State Survey to help some later investigator as it has helped him, an important function as far as the economic development of the State is concerned will have been accomplished. Its relations to educational and purely scientific interests we do not touch.

§ 5. Promoter and land owner.

We are now prepared to better understand the use of the "man who wants an option," whom we have agreed to call for

short the promoter. The coal under a piece of land may not pay to work by itself. Prof. Pumpelly has shown very clearly that large coal mines mine more economically, and pay a larger percentage of the selling price of their coal to the workmen. Land should then be gathered into aggregates for working, large enough to give a chance for the most economical mining. Moreover, before any mining is done there must be considerable exploratory work, to determine how best to mine the coal, where the lowest spots best for sinking shafts may be, and where are the channels cutting out the coal which should be avoided. But no man can be expected to go to the expense of exploring and drilling for coal, unless assured that some of the increased value which will come to all the land around a successful exploration will be to his benefit. In all this there is no question of over-reaching anyone. It is a plain business proposition. This gathering of the coal rights of land into developable tracts is the work of the promoter.

How should such offers be met?

In the first place unitedly. Owners of adjoining tracts should agree on options or terms to the same party, or if they choose should co-operate in a company for developing their lands themselves. If certain owners stand off and refuse to unite with their neighbors, the very best places for shafts, and the most economical mining, may be impracticable. Suppose for instance a want or channel runs diagonally through a quarter section so as to isolate in one corner a few acres of good thick coal. That coal might be profitably developed and taken out in connection with the coal on the adjacent farm, but if that is leased to a different party or the neighbor refuses to lease, it becomes practically worthless, except to one man who can later name his own price.*

On the other hand, if a few big companies get hold of all the land except a few small pieces not worth working separately, they can force the remaining owners to take about what they choose to offer. This has been very notably the case in the Mesabi iron range in Minnesota. A few companies control the situation. This is an age of combination, and combined action will prove most successful. The owner who, not having land enough for independent working, refuses to unite in joint negotiation with his

*Near St. Charles there is some coal on the N. E. corner of the N. W. quarter of Sec. 17, which could best be handled through the Somers No. 2 shaft, and perhaps is only worth handling through it.

neighbors, may injure them, but is far more likely to damage himself.

Secondly, the promoter should be met fairly. He is about to risk some money in exploring, and if one wishes to aid in the progress of the country, and give men of moderate means a chance to have a share in it, one should not demand too much money in advance for coal rights, provided the terms in case the explorations are satisfactory give a fair and customary share of the profit to the land owner, either in the shape of royalty on the output, or a lump sum for the sale of the coal rights. But what is too much? And what is a fair share? These are difficult questions to answer, for much depends on local conditions, but we shall try to throw some light on them in the remaining sections.

It is well to remember that a considerable sum of money must be spent in preliminary testing, and, if that proves promising, in preliminary equipment, before any returns are realized, and it is obvious that in making, for example, present cash payments for coal rights, a large margin of prospective profit must be allowed, to tempt a man to incur cash outlay. Without much doubt the most satisfactory plan is to have the land owner assume part of the risk and have his profits depend upon the success of the venture, by making the payment to him come (outside a small cash payment to bind the bargain and as a guarantee of genuine work), in the shape of royalties, i. e., a fixed sum per ton for each ton of coal mined. This has been the almost universal rule in Michigan, the royalties running from 6 to 15 cents per ton. The more certain the amount and the greater the thickness of the coal, the higher the royalty that may fairly be demanded. Probably 8 cents is the most common figure.

§ 6. Labor value of coal.

The value of coal as of everything else depends on two factors, the cost of production, and the scarcity of the material. It is the last value only which the land owner possesses, and with which we wish to deal, and yet we cannot easily separate the two sources of value. The scarcity is almost invariably in any article, certainly so in coal, not absolute, but the scarcity of sources of supply that will yield the coal so that it can be laid down in a given market, say Bay City, at a given cost.

To make the matter more practical, the scarcity value of Michigan coal is the difference between the cost of the production, and

the cost (including labor in the mines *and* transportation, etc.), of delivering coal from States where there is more than they know what to do with, like Ohio and Pennsylvania, of the same grade in the same market. This is with the proviso that, as at present, there is not enough of the local coal produced to supply the demand for soft coal, and some imported coal is needed to make up the difference. If and when the mines in the neighborhood of Saginaw can supply more coal than the local market can take up, the price will fall, until one of two things will happen. Either the mines or parts of mines producing at greatest expense (on account of narrowness of seam, amount of water to pump, insufficient transportation facilities, poor roof, etc.), will shut down, as the price has fallen where they can make no profit, or the surplus coal will be sent away and replace Ohio coal elsewhere until the market is made large enough to take the supply. The farther it goes south, the greater will be the freight charges, and the less the amount which the mine will receive. For instance, at Lansing Hocking Valley and Saginaw Valley are in close competition, at about \$2.05 per ton. The freight charges on the former are \$1.40 per ton, on the latter \$0.70 per ton. The mine in one case gets 65 cents, in the other \$1.35 per ton, and if it costs the same to mine the scarcity value would be 70 cents a ton. But as I have in the next section remarked, it costs nearly 1.30 a ton to mine coal in Michigan, leaving only five cents margin of advantage of position to the Michigan coal. Until the freight rates are revised, therefore, Michigan coal cannot go much farther south, unless the average cost of mining decreases.

Before the independent mines producing coal more expensively are shut down, the laborers, unless they are effectively organized, will be ground down to the last notch, and the easiest mined coal gouged out. Finally the mines which are unwisely planned, or worked with insufficient capital, or on an uneconomically small scale, which Prof. Pumpelly has shown is generally true of the small mines, will have to shut down. In short, first the laborers and then the small operators, or vice versa, depending on which is best organized, will suffer. This is the process known in the financial columns of the papers as "getting the business into strong hands." In other words the control of the production becomes vested in a few men, who directly through a trust or indirectly by a general understanding, determine how much coal can be mined each year to best advantage, and can afford, as they

work on a large scale, to keep reserves of coal until later and shut down the mines they can least profitably work.

It is plain that the first alternative suggested, that of crowding the weaker mines to the wall, is not pleasant. It produces the misery, the constant strife between workmen who must fight for a living wage, and operators who *must* grind if they keep in business, with frequent strikes and the bloodshed and misery that may attend them. Yet this was the normal or rather the regular way of keeping down the production in the States to the south of us, where there is vastly more coal than the country can consume, and here we find the coal mine operators of one district subscribing to the strike funds of another, practically paying the workmen to strike, that thereby they may keep down a rival production.*

Now it is obvious that by this policy of every man for himself and the devil take the hindmost, the value of coal lands as such is reduced down to nothing. It is only those tracts exceptionally rich and near the railroads or market that are worth anything, and that in proportion to these exceptional advantages. It is obvious, also, that labor cost will be whittled down to the lowest point.

Finally, from a geological point of view most important, it leads to a development of the resources that is a synonym for wastes. Instead of the coal being mined cleanly, the richest and handiest parts are gouged out, much left for pillars, as little timbering as possible done, and the rest left, perhaps in such condition that it can never be safely or profitably worked, certainly so that the total expense will be much greater than had a good job been done at first.

Let us get some figures of coal which we may be sure will be nearly minimum from those over-productive regions. Mr. W. J. Nicolls† gives the following items of cost as typical in the bituminous coal fields of Pennsylvania:

	Cents.	Cents.
5 per cent interest on capital invested.....	5	
Cost of haulage.....	7	
Cost of deadwork, drifts, shafts, etc.....	3	
Cost of superintendence.....	2	
Office expenses	3	20
Contract price to miners (35 to 40 cents).....	35	55
Royalty per 2,000 lbs.....	10	65

*Mineral Industry, 1897, p. 163, "the chief cause of the strike was that in a large part of the western bituminous fields, mine work is not regular, and the miners' wages are thereby reduced to a very low point. The existing coal mines of the United States could probably supply a demand 50 per cent greater than at present."

†Story of American coals, 1897.

The average selling price per ton of 2,240 lbs.* was 70 cents, or say 62.5 cents per 2,000 lbs., showing 2.5 cents loss on every ton raised. In other words, unless there was some profit from slack ignored by Nicolls, the royalty was too much.

According to Mineral Industry, 1897, the price of coal averaged in 1896 and 1897 respectively, 78 and 77 cents in Ohio, 66 and 67 cents in Pennsylvania. It is doubtful if there is a ten cent margin for profit and royalty and interest on capital at those figures. Orton, speaking for Ohio, says†: "Our coal will never be properly mined or properly burned so long as it costs at the mine less than \$1 per ton. The question of waste demands immediate and serious consideration."

It will be noticed that the wages to miners are reckoned by the ton, and a weighman employed partially by the company and partially by the men, keeps track of the product of each miner. But there is a "fruitful source of discord"‡ in the method of weighing the coal, as to whether it should be screened so as to remove the dirt and small coal before weighing or not, and if so how coarse the mesh of the screen should be. As the screened coarse lump coal is worth a good deal more than the screenings or "slack," (see Plate VI), and the size of the coal depends largely on the care of the men in getting it out and handling it, the operators used to insist on the coal being screened and paid only for that passing over a certain sized mesh. Since, however, there has sprung up quite a demand for the smaller sizes of coal, pea coal, and buckwheat and so forth, the operators have begun to find much profit in this smaller sized coal, more if they could get it for nothing than in the larger, and to encourage its production, and many a controversy has turned on the size of the screen. In Sebewaing in the summer of 1897 there was a strike, the men demanding a $\frac{3}{4}$ inch screen, instead of $1\frac{1}{4}$ inch as theretofore. It was settled, as seems to be the general tendency, by paying for the coal by weight before screening, or as it is called, "run of the mine." At present, however, the use of the $\frac{3}{4}$ inch screen is universal in Michigan for basing wages. From a paper we gather the following statement of wages paid at Virden in connection with the notorious strike of 1898:

*There is always a juggling in figures in coal over the long ton of 2,240 lbs. and the short one of 2,000 lbs. It is a pity that the metric ton, which is practically the long ton, is not introduced to the exclusion of all others.

†Orton, Ohio, 1893, p. 269.

‡Orton, Ohio, 1898, p. 155.



CARS OF LUMP AND SLACK AT STANDARD MINE.

"Prior to the summer of 1897 the pay was 25 cents a ton, mine run. Some men had worked at 55 cents a ton, screened coal, which was about equal to 28 cents a ton, mine run, though the relative value of wages per ton, mine run, and screened coal, varies greatly in different mines, as some coal is much more fragile than others. In the strike the miners demanded 40 cents per ton, mine run."

The only remedy the operator has against workmen's carelessness in blowing the coal to pieces, in case the wages are based on the run of the mine, is to dock, fine or discharge them. On the other hand, various parts of the same mine vary so in brittleness that payments by amount of screened coal are very irregular and uncertain.

We notice from above figures that the rate of wages in the West is higher than in Pennsylvania, so that we must replace the 35 to 40 cents a ton, mine run, (?) by at least 50 cents, to find the labor cost of mining in Lower Michigan.*

Something should also be added for the extra amount of water which will have to be handled, and we shall find from 75 cents to one dollar as probably what should be the minimum cost of mining coal in Lower Michigan. I doubt if this is attained in any mine; \$1.30 is nearer the mark still. The labor commissioner's report makes it \$1.38 in 1900. But of course much also depends upon the thickness of the seam. In Missouri a 22-inch coal seam is mined for four cents a bushel, i. e., one dollar per ton of 2,000 pounds clean coal, while in the Osage district a 14-inch coal costs about a cent more a bushel (\$1.25) in consideration of the difficulty of mining. As the entries and drift must be about the same height, no matter how thin the coal, the expense of deadwork† will also remain constant per acre, i. e., increase proportionally to the thinning of the coal when divided by the tonnage produced. It is said that a coal seam four or five feet thick can be worked as economically as one thicker, but as the seam becomes thinner the cost rapidly rises, and somewhere between one foot and two feet comes the thickness where it ceases to pay, depending on the price of coal, its freedom from sulphur, and other desirable properties. In Ohio‡ for every three inches decrease in thickness below four feet the miner was paid five cents per ton additional, down to two feet, no coal being mined except in rare cases below this thickness.

*A few years ago in Jackson and Corunna, according to Lawton's 1883 report, they were paying the miners 80 cents a ton for coal, and the cost was \$1.30 a ton, not including royalty. The scale price for 1901 is 86 cents per ton for pick mining of screened coal. See Michigan Miner, April, 1901, for complete scale.

†Lifting the fire-clay, taking out weak roof, known as draw slate, etc.

‡Orton, 1894, p. 247.

From the fact that in Missouri seams 14, 20 and 22 inches thick are worked and seams averaging two feet thick are assumed to make a profit of ten cents a ton at \$1.30, we may infer that there the limit of working is about a foot and a half, costing about \$1.30 to mine. The average thickness of the coal seams of Newcastle, England, is, according to the *Encyclopedia Americana*, three feet, and of the Pennsylvania bituminous area three and thirty-three one-hundredths feet. So we see, comparing the cost in Pennsylvania given above, that taking a three foot seam as a standard, the cost of mining is somewhere about inversely proportional to the thickness of the coal. If it cost 70 cents a ton to mine a three foot seam it would cost \$1.40 or thereabouts to mine a foot and a half seam and \$2.10 to mine a foot seam. (At Grand Ledge they were in 1899 paying \$1.10, mine run, per ton to the miners and selling the coal for \$2.00. The seam is about a foot and a half thick and there did not seem to be much profit in the business. In 1901 the price of coal was from \$2.30 to \$2.00 and the miners, each delivering his own car to the shaft or tippie, received 30 cents per car of 500 lbs.) Now as the price of bituminous coal ranges in the Saginaw Valley between \$1.40 and \$2.10,* we are not surprised to find that beds 15 inches and 18 inches thick have been picked into here and there, but never put on the market in a large way. Taking the selling price to be as given above on the average \$1.42 $\frac{1}{2}$, if we assume the royalty or profit to have been 10 to 15 cents a ton, which the report of the Mineral Commissioners indicate as a prevailing figure† the cost will be \$1.30, exactly what Lawton reports the cost of working at Corunna. But the probability is that the thickness of the coal mined averaged not over three feet. So it would not be safe to figure at present in Michigan on a cost of less than \$1.30 a foot for two and a half to three foot seam, though if the roof was good and sandstone "wants" and channels and faults not too abundant, and if the water could be easily handled, the cost might be cut down by nearly one-half.

§ 7. Scarcity value of coal.

We have discussed the cost of producing coal and we have seen that the thickness of the seam makes much difference, that while

*In 1887, \$1.41; in 1896, \$1.44, according to *Mineral Industry*, 1897, p. 161; according to D. A. Patterson in 1898, \$1.44; in 1897, \$1.46, and in 1896, \$1.62 at the mine. The report of the Commissioner of Labor for 1900 and 1901 makes the cost per ton for the entire output; in 1899, \$1.31; in 1900, \$1.38.

†Lawton, 1186; Knight, 1895, but in the Saginaw Valley, in spite of the better quality of coal there, 8 cents is a more prevalent figure.

a three or four foot seam may not cost more than 70 cents a ton to mine, the thinner the seam the more the price will rise until a seam about a foot and a half thick will cost as much to mine as to ship from outside. We have pointed out the evils of over-production also. We now come to the question, how much coal is there in Michigan of the various thicknesses? Is it possible to break the market with coal, or must we to do this draw on coal so thin that it will be cheaper to import from Pennsylvania and Ohio.

The coal basin of Michigan has been supposed to cover from 6,500 to 8,000 square miles.*

As I have before remarked, its extent under the northern highlands is quite uncertain. Coal is well known to occur in Arenac county. Mr. Holcroft's men found coal fragments around the headwaters of the Tittabawassee and Salt Rivers, and Mr. T. T. Bates of Traverse City reports that his woodsmen found a ledge (boulder?) containing coal as far north as Roscommon county, and the wells at Gladwin and Big Rapids indicate that the coal extends considerably to the north of them. It certainly stops considerably south of Grayling. From the map (Plate I) we may estimate the area of the whole basin, including the Parma sandstone, as 11,234 square miles, though this estimate may be 500 square miles out of the way. But by no means all of this is underlain with coal. We have to allow, as have geologists in other States, for various kinds of erosion which have cut out the coal, and not only for the loss through sandstone and drift channels, but for the coal made unworkable thereby. Orton in Ohio allowed 10 per cent. Any estimate can at the present state of affairs be but crude, but if I take a number of fairly reliable drill records from the various geological reports, those of the Saginaw Board of Trade and private sources, many put down for coal and likely to exaggerate it, but others for salt, etc., likely to neglect it, I find the following results: Out of 110 holes put down in the coal basin, 43 have not any coal reported (39 per cent.), 7 have coal seams, but probably less than a foot thick (6.3 per cent), 11 between one and two feet of coal (10 per cent), 20 between two and three feet (18.2 per cent), 12 between three and four feet (10.8 per cent), 17 over four (15.5 per cent). From this we may provisionally infer that 61 per cent of the basin

*6,500 Keyes, Iowa, 1892; 6,700, according to A. Winchell, 1861, and U. S. G. S. 18th Annual Report, part 5, p. 353; 7,000 Mineral Industry, 1892; 8,000 Rominger, Geol. Sur. Mich. III, Pt. I, p. 345; 13,350 H. D. Rogers in Harper's Monthly XXIX, 1894, p. 163, Holmes, Mines and Minerals, September, 1899, 9,810 square miles.

is underlain with coal, but only about one-third of the basin with workable coal. Some drillers of experience tell me that even this is an over-estimate and only one hole in five or six is worth anything. To the figures given I may add from more recent data, that of 234 holes put down west of Bay City 46 (19.7 per cent.), show less than a foot of coal, 30 (12.8 per cent), between one and two feet, 65 (27.8 per cent), between two and three feet, 66 (28.2 per cent), between three and four feet, 29 (11.5 per cent), over four feet. These holes will give too high an average because where one hole has struck good coal, a number have been put down near it. On the other hand, they would hardly average to go half through the coal measures, so that there is undoubtedly some coal which they do not show. This coal will average 2.86 feet (west of Bay City, 2.4 feet) thick, or for the whole basin 1.75 feet thick. But if we take into account only the coal two feet thick or over, and allow but 1,000 tons to the acre to be yielded (and though modern practice can do much better, not much better is done in Michigan), and assume the area of the coal basin to be only 6,500 miles, we still have indicated 8,025,600,000 tons, nearly half in workable seams.* The greatest uncertainty in the situation is undoubtedly along the northern rim of the basin, where there may be much more coal than can be anticipated, or much less. One thing, however, is practically certain, the depth of drift and the consequent expense of development will be much greater. I think also that preglacial erosion will prove to be greater.

Now let us see what consumption we may count upon. The population of the coal basin was, by the census of 1890, 752,695, of the State, 2,093,899, and as the population of the State doubled in the interval 1870-1890, there must be about 1,000,000 people in the coal basin now. In 1900 the population of the state proved to be only 2,420,982. The consumption of bituminous coal in the United States was in 1889, 85,383,059 tons, valued at \$94,000,000; in 1890, 95,961,595 tons; in 1897, 147,557,980 tons; in 1899, 191,456,350; in 1900, 220,592,239 tons of 2,000 pounds†, while the population was in 1890 63,069,756 and in 1897 was supposed to be about 70,000,000. The census of 1900 made it 76,304,799. Thus for the United States in general two to three tons of coal were used per inhabitant, and

*Even this may be too large, yet Pennsylvania with 9,000 square miles coal area is estimated in the Encyclopedia Americana to have 33,547,000,000 tons of bituminous coal, four times as much with an area of coal measures not 50 per cent greater and with only about twice the average thickness of the coal seam.

†Eleventh Census report, and Mineral Industry for 1892 and 1897.

at this rate we could consume two to three million tons of coal in the coal basin alone. I have not been able to find what the consumption really is, but surely much less. A vast amount of coal is consumed in a few industrial centers like Pittsburg, which raises the average for the United States. The Saginaw Valley has no city of the first rank, and the use of wood, slabs, etc., for fuel is hardly out of date. But as wood ceases to be used as steam fuel, and as glass, Portland cement, sugar and other large industries come in, we may expect the consumption of coal in the future to grow much faster than does the population. We can get minimum figures by taking the annual product for 1890, 74,974 tons, and adding to it amounts shipped in* by lake that year, viz., to Bay City, 84,000 tons; to Detroit, 90,000 tons; to Port Huron, 37,200 tons, and to Grand Haven about as much, i. e., about 300,000 tons. There was probably at least as much shipped by rail and to smaller ports, which we cannot estimate, but we see that the per capita consumption of coal was still quite low, probably not much more than half a ton per head of bituminous coal, and we see also that the domestic supply is but a fraction of that. Thus if coal can be produced in Michigan so as to drive out imported Ohio and Pennsylvania coal, there is a large market, and with proper industrial development there ought to be a chance to produce twice as much coal as at present without seriously breaking the price, provided the Ohio coal is sold as close as it can be and rates on shipping it in are not lowered. They are now only half to a third that charged for Michigan coal per ton mile, so that it is probable that the adjustment will be the other way, in favor of Michigan coal. However, there will always be some importation of varieties of coal having some especially desirable quality. It must also be remembered that lake freights are so low (25 cents to Cleveland) that the great coal shipping ports of Lake Erie are but a few miles off by rail.

Ohio and Pennsylvania have immensely larger resources of coal,† so that if owing to any temporary glut of the Michigan market or strike there, our coal were to be exported thither it would be a sheer carrying of coals to Newcastle.

Thus we must look north and west of our own State (or possibly we might supply the Sudbury district in Canada) for our market.

*U. S. Navy Department 1892, "Coaling, Repairing and Docking facilities of the ports of the world," p. 8.
†Ohio, 1894, p. 155.

The above estimates of the quantity of Michigan coal allow for a waste of over a third in mining, and, if the resources of the State are husbanded and not given over to that form of development which is really squandering, greater waste can be largely avoided. The plan of a part of the Porter coal mine in Jackson (Fig. 5) shows the wastefulness of the old room or chamber system of mining and the amount of coal left in pillars, for only the part unhatched was mined out. A foot of coal over an acre would yield,* as coal varies from 1,240 to 1,340 ounces per cubic foot in specific weight, on an average 1,752 tons. But it was not so long ago common to estimate only 1,000 tons to the acre, i. e., only 56½ per cent of the theoretically possible was available.

In Missouri, Winslow† figures on obtaining 1,250 out of a theoretical 1,700, i. e., five-eighths.

In Bristol, England, 1,500 tons to the acre are expected. Orton claimed that in 1884 the best practice gained but ⅔ of the theoretical amount. Agreeing with him, Professor Sperr of the Michigan College of Mines tells me that it was the custom to leave 40 per cent of the coal underground, and when some years ago the engineer of the Columbus, Hocking Valley & Toledo R. R. read a paper before the Ohio Society of Engineers, in which he claimed that 85 per cent could be saved, it was received with jeering incredulity. But now up to 95 per cent is saved, and in his estimates in 1893 Orton‡ allows only 20 per cent for mining loss. The leases of the railroad above mentioned provided that the lessor should mine all the coal. In England a distinct improvement in the amount of coal gained has been obtained by making the leases payable per foot per acre and not per ton extracted.

But for such good and economical mining it is necessary that there should be a profit on the coal. If the price falls too low the cheapest method of mining, no matter how much the waste, must be adopted. It is for this reason that Professor Orton was led to say, as above quoted, that no coal was ever properly mined or burned in Ohio at less than \$1.00 a ton.

The method of saving the coal most thoroughly is known as the long-wall system of mining, which in its application to the mining of thin seams with a weak roof is described by Winslow.§ It is probable that we cannot do quite as well in Michigan, as the shat-

*See tests of specific gravity in Table A.

†Mo., 1891, p. 49.

‡Orton, Ohio, 1893, preface p. x. estimates for Ohio 12,000,000,000 tons above drainage.

§Mo., 1891, App. A., p. 178.

tering of the roof in caving would in many cases let in too much water. Again the long wall system to be effectively worked, requires a rather steady production, which very few Michigan mines have as yet attained.

As we have said a good deal concerning the waste of coal and other possible evils of a possible over-production, and as some one may blame us for not suggesting any remedies in case such evils appear, we shall mention those remedies that suggest themselves as possible now, before any party feelings can be excited, for there is no immediate call for the application of any of them.

1. State ownership of the coal mines and control of the output as in Rhenish Prussia. This works very well.

2. Combination of the producers to fix output. This is generally known as a trust. No purely local combination could so check the output as to raise prices much above their present level, as the competition of imported coal is so great. Ohio coal now comes as far as Flint. This plan has been practically adopted by the chiefs of the anthracite trade and is preferable to unrestricted competition. Many of the mines near Saginaw now sell through one agent.

3. Regulation by a State supervisor, who should on the basis of the amount of coal consumed the previous year, and allowing a normal rate of increase of consumption, assign to each operating company its due proportion of the output, according to the amount of productive territory which it controlled, or number of producing shafts, making allowances for local demands or exports. This third plan has never been put in operation, so far as I know, but it would be practically a pool or trust with the pooling officer a State official. He should be a man of judicial and scientific character, and his duties would be in line with those of the Commissioners of Mineral and Labor Statistics, or the new Coal Mine Inspector, and if planned and worked, like the State Salt Inspection, with the good will of all parties, it would be a blessing all around. It would require a rare combination of abilities in the commissioner, and the chances are that he would soon find himself in hot water. Such a commissioner should try to keep the price up to a point where coal could be mined without actual loss down to $1\frac{1}{2}$ feet thick, and yet down below the price of imported coal. As the price of coal is likely to remain much less in Ohio and Pennsylvania than in Michigan and freight rates are low, he

could hardly even by mistake or corruption so limit the production as to produce extortionate rates.

We may sum the situation up as follows:

(1). Local production is at present only a fraction of local consumption (in 1896, 83,150 tons; 1897, 188,638 tons; in 1898, 290,711 tons; in 1899, 600,000 tons; for 12 months ending Dec. 1, 1900, 843,476 tons, but is very rapidly increasing. This original statement may be still true, though a good deal of our coal now crosses Lake Michigan.

(2). If the industrial development is such that the local consumption becomes equal to that of the United States per capita, a four-fold increase of production will be taken care of.

(3). But even 1,000,000 tons per annum, which will be reached in 1901, would imply but the mining out of a quarter section of four foot coal, so that over-production is quite possible.

(4). The total product of the past (1,861,444 tons, up to 1898), is not an appreciable fraction of the resources.

(5). The local product should look to the local market, north and west.*

(6). Probably a sudden four-fold increase of present production would overstock the market.

PRODUCTION OF COAL IN MICHIGAN FOR 1900, BY COUNTIES.†

County.	Production. Short ton.	Value.
Bay	190,814	\$283,184
Eaton	4,530	8,770
Genesee	300	300
Huron	5,953	11,142
Jackson	23,817	43,838
Saginaw	601,112	872,496
Shiawassee	23,443	40,413
Total	849,475	\$1,259,693

PRODUCTION OF COAL IN MICHIGAN, 1880-1900.*

Year.	Production Short ton.	Value.
1880	123,053	Not given
1881	130,130	" "
1882	135,339	" "
1883	71,296	" "
1884	36,712	" "
1885	45,178	\$75,000
1886	60,434	90,651
1887	71,461	107,191
1888	81,407	136,221
1889	87,431	115,011
1890	74,977	149,195
1891	80,307	133,387
1892	77,990	121,314
1893	45,979	82,462
1894	70,022	103,049
1895	112,323	180,016
1896	92,882	150,631
1897	223,592	325,416
1898	315,722	462,711
1899	624,708	870,152
1900	849,475	1,259,693
	3,396,417	

*Events have verified this statement.

†From U. S. Geol. Survey, and State Labor Commissioner, whose bulletins one should see for latest statistical data. Product for year ending December 1, 1901, 1,004,104 tons.

§ 8. Value of coal royalties.

We are now within sight of the answer to our question: What is the value of the coal under the land?

If the land is in the basin and the chance is the same as for the basin in general an acre would contain 44.5 per cent of land with coal over two feet thick. This would for the whole area average 1.56 feet thick. Supposing this to cost \$1.30 a ton and sell for \$1.40 a ton, we could reckon on a profit of ten cents a ton, and allowing 2,500 tons to the acre to be available (1,600 tons per foot per acre) we should have \$250 as the value of the coal beneath an acre.

But this cannot be taken as its cash value, for the price may fall below \$1.40 and the cost may be above or below \$1.30. It is better to mine a little thick coal than the same amount spread out. Finally, and most important, by no possibility can the coal be all taken out immediately and the present value of \$250 to be paid in installments through a series of years is by no means the same as \$250 cash in hand. So that before we discuss its present cash value we must consider a little more closely the value of coal in the shape of royalties.

We have said above that under certain doubtful suppositions the coal may be worth so much a ton. If the coal is thicker it is worth more, if thinner less. The more information we have on this point the less of speculation and more of certainty the investment becomes. The more uncertain an investment the larger must be the prospective profit to tempt one into it, and thus we cannot expect a man to pay the full speculative value of land. The more exploratory borings have been made the nearer we may expect to get the value indicated by the borings, and the higher the royalty which may fairly be demanded. These borings are part of the initial deadwork. The Michigan Miner says that one company has expended \$10,000 in borings alone.* So let us turn from theoretical and hypothetical data, and see what men have been practically willing to give. We have noticed that in Pennsylvania Nicolls assumes a royalty of ten cents a ton, and we find away off in Missouri Winslow assuming the same rate as the landowner's profit†. The Commissioners of Mineral Statistics give the royalties at Jackson and Corunna‡ at 10 to 15 cents for screened coal. I am told that

*January, 1899, p. 10.

†Mo., 1891, p. 49.

‡Lawton, 1885, 1896, Knight, 1895.

at Grand Ledge 15 cents a ton is sometimes demanded. Some years ago in Ohio* they were paying 15 to 30 cents royalty on lump coal when they were paying miners 35 cents a ton (four cents more when the seam was less than four feet thick for every two inches below four feet). In Pennsylvania the Girard estate which holds some very fine anthracite coal lands, reports a royalty of 30½ cents and the Encyclopedia Americana reports as a common form of lease 25 cents a ton royalty, with 50,000 tons a year to be mined and fifteen years term of lease. Mines and Minerals quotes Pennsylvania bituminous coal lands at from \$25 to \$50 an acre, with royalties for non-coking coal from 5 cents to 12½ cents a ton. Mr. Ward says that 5 cents is a common rate.

As to whether the royalty is based on the ton of screened coal or not, we come upon the very same source of dissatisfaction, between the fee owner, and the operator who pays the royalty, that we found between operator and workmen. The operator has not the same reason for demanding payment to be only per screened ton and it will be found better if the royalty is upon the run of the mine. Five cents a ton, "mine run," will nearly or quite equal eight cents a ton on screened coal, though the proportions vary in different mines. It will then be more to the operator's interest to see that the coal comes out in as good condition as possible. Whereas, if there is a good demand for screenings and he gets them free of payment to the fee owner or miner, it might pay him to let the coal be smashed up, thus losing value for the fee owner, miner and community. Documents leasing the right to mine coal under a royalty† often provide that all the coal be taken (down to a reasonable thickness) and royalty be paid on the same. Otherwise there will be a temptation as the margin of profit dwindles to leave much of the coal in pillars where it cannot be extracted later, to save timbering, to the loss of the fee owner and the community. For this reason English authorities prefer‡ leasing coal by the acre, rather than by the ton, for it produces "better results for the landowner and closer working by the operator, and of course a greater yield per acre."

To see that the operator does thus mine all the coal requires a survey from time to time (usually monthly; the old work does not all have to be done over again). But the extra cost is well repaid,

*Orton, Ohio, 1884, p. 775.

†Seesman and Peters of Saginaw print a variety of forms of blank leases.

‡Encyclopedia Americana, p. 228.

and progressive States require the filing of mine maps in any case, since if more than one company has worked or is working in a district there is serious danger of fatal accidents from breaking into old water or gas filled workings.* Moreover the position of exploratory borings and artesian wells should be marked on the map for avoidance.

The question may arise as to other minerals or substances of value found in mining. For instance at one time they paid five cents a ton more for sulphide of iron in Jackson, than for coal. The fire-clay beneath the coal may also be of value. Ordinarily the presence of sulphide of iron will hurt the coal more than its independent value will amount to, and usually a certain amount of fire-clay will have to be taken in the deadwork to make entries high enough for hauling, unless the coal seam is extra thick, and the operator may well make all he can to eke out the profits of narrow seams. Other substances, such as iron ore, may at times have some value, but ordinarily the mineral rights for other substances than coal may be included with the coal.

It may be asked whether since the profits increase rapidly with the thickness up to four feet, the royalty should not also. While this is theoretically true, and in England they do thus survey the coal and lease it by the foot per acre, the extra expense of such a *survey* is considerable. A rough adjustment might be made according to the preliminary borings by decreasing or increasing the thickness of the coal which it was allowable to leave so that the average thickness of that taken should be two and one-half to three feet. Of course, if the coal were well known to be thick, a proportionally large royalty could be obtained.

It is, however, not uncommon to grade the royalty to be paid according to the selling price of the product, and this is eminently fair. In Appendix A is given part of a lease given in the iron business providing for a sliding scale royalty, which the Cleveland-Cliffs Company permit me to publish.

It is also the custom, as has been noticed above, to provide that the leaseholder shall mine or at least pay royalty on not less than a certain number of tons each year, so as to insure the fee-holder some steady income. It is obvious, however, that a large number of operators leasing independently of each other might be led to

*The Sebewainz district is already in this predicament, and if the Pere Marquette No. 1, which is now shut down had not been mapped, it might be awkward for the Saginaw mine.

thus guarantee an output larger than the market could possibly take, and thus bring on the evils of over-production cited above. So that it is for the best interest of all to make this amount small, or waive it altogether if the price falls too low. As it is to the interest of the operator to go ahead and get back the money invested in plant and deadwork as soon as possible, it will not ordinarily be necessary to force him ahead, while the exigencies of mining may make it more economical to mine now here and now there.

§ 9. Present worth of coal rights and royalties.

We come at last to consider what is the present worth or value of these royalties and leases for a term of years; in other words, of a body of coal which cannot be at once turned into cash. Suppose I am to get \$100 in a year. What is it worth to me now? Obviously the sum of money which at the current rate of interest will yield me \$100 in a year, i. e., \$95.24 at five per cent; but as there is a certain advantage in having my \$95.24 now, for I might prefer to spend it, or use it to save house rent, or in some other way in which it would earn more than five per cent, or at least I thought so, and as a bird in the hand is worth two in the bush, I should be likely to prefer the cash in hand unless the rate of interest were very good. Applying this to buying coal rights, we must also remember that many coal operators would be willing to go shares in profits in the shape of royalties on prospective profits, who would not have the cash to buy outright, or if they did would think they could earn a larger rate of interest upon it otherwise. Moreover, there is not nearly the risk involved in leasing on a royalty as in buying the land outright, and as men of smaller means can enter the competition for land it will often be more keen than for land to be bought outright. Thus a large discount from the value of coal as indicated by the customary royalties will usually be necessary to find its present worth.

Much also depends upon how quickly the coal can be mined. If the coal can all be mined in five years the return from royalties will be sooner and the present worth greater than if it takes the more ordinary term of a coal lease—15 to 25 years. The Star mine at Jackson was leased for a 30-year term at 15 cents royalty.

The following little table shows the present worth at five per cent of a royalty of ten cents a ton on 100 tons of coal, provided this royalty is divided into equal payments over a term of years, for various terms up to 60 years.

For other rates of interest the time over which the payments must be stretched to have a given present worth is in a rough way proportional to the rate of interest, e. g., if the rate of interest assumed were eight per cent and the payments distributed over $(40 \div 8 \times 5)$ 25 years their present worth would be about \$4.29.

TABLE OF PRESENT WORTHS. FIVE PER CENT.*

Terms of years.	Present worth of \$10 distributed in equal payments.
5	\$8 66
10	7 72
15	6 92
20	6 22
25	5 64
30	5 13
35	4 68
40	4 29
45	3 95
50	3 65
55	3 39
60	3 16

Now let us see what prices have been offered outright for coal lands.

Mines and Minerals had this to say in August, 1900: "Bituminous coal lands such as you describe sell in Pennsylvania at the present time for \$25 to \$50 an acre." . . . There are a great many royalty leases in this State and the royalties on bituminous coal, non-coking, vary from 5 to 12½ cents per ton. Coking coal royalties are higher, and we know of one such royalty of 17½ cents a ton.

In Missouri where Winslow estimates profits at ten cents per ton mined and 2,500 tons to the acre, coal rights are said to be† but a few dollars, seldom over \$5.00 an acre. The United States‡

*The formulæ used are, if (y) is present worth, (c) total payment equally distributed over a term of years (x), and (i) the rate of interest:

$$y = \frac{c}{ix} \left(1 - \frac{1}{(1+i)^x} \right)$$

and if (u) is present worth at rate of interest (r) for the term of years (v), and if

$$v = x [\log (1+i) + \log (1+r)]$$

$$= \text{nearly } x (1+r)$$

then:

$$u = y [i \log (1+r) + r \log (1+i)]$$

$$= \text{nearly } y.$$

From these formulæ it follows that the present worth if the rate of interest allowed is twice as great will be very nearly the same as though the payment were distributed over twice the period, and in the same ratio for other rates of interest. The table can also be used supposing that the royalties were paid at more frequent intervals, by replacing years by number of payments, and the interest that is earned between payments. For instance the present worth of a royalty of ten cents a ton payable semi-annually in equal installments for a term of ten years on 100 tons of coal would be at five per cent semi-annually \$6.22, the total payments on the royalty being \$10. Finally for longer terms than sixty payments the value of the present worth is nearly the total payment divided by the rate of interest and the number of payments.

†Mo., 1891, p. 50.

‡Law of Minerals and Mining in the U. S., p. 549.

demands for public coal lands \$20 an acre if within 15 miles of a railroad, \$10 if not within that distance. In Michigan offers of \$7.00 an acre are known to me. Now this last offer would mean at 5 per cent an equivalent to only 34 cents total royalty or 10 cents a ton royalty on 3.5 tons of coal per acre, and the production would last at this rate at 2,500 tons to the acre, 714 years. This production may seem absurdly small, and yet if we stop and think, it is far more than the pro rata share of the production or for that matter the consumption of the Lower Peninsula, for if we take the productive area of the coal basin as but 4,000 square miles, i. e., 2,550,000 acres, we see that the present production or consumption is but a fraction of a ton per acre. If, in other words, all the land of the coal basin were leased at 30 cents per acre royalty, the *lessors* would be bound to lose heavily. Thus for a tract to be worth for the coal rights \$7.00 an acre the buyer must depend upon exceptional advantages as shown in borings or other explorations, and on nearness to market. As long as the consumption is at the rate of only about a tenth of a ton per acre of coal land the present value of land for coal cannot average more than 20 to 30 cents an acre. The present value of any particular tract will vary from that, according as it is favored in nearness to market and shipping facilities, and as it is likely as shown by borings, etc., to be better or worse than the average, and the general value of coal lands will rise as the consumption of coal increases.

APPENDIX A TO CHAPTER VI.

Extract from form of lease of Cleveland-Cliffs Mining Co., illustrating provisions for royalties on a sliding scale:

Royalty per ton.—*Fourth.* The second party shall promptly pay at the times hereinafter named, to the party of the first part, its successors or assigns, royalty on all iron ore, mined and removed from said premises or used thereon, during the existence of this lease, at the rate of not less than seven (7) cents per ton of 2,240 pounds, which royalty will vary with the price of the ore either market or actual as per schedule below. If the average market price of ore of like kind and quality at Cleveland, Ohio, upon dock at Lake Erie ports, for the three months preceding the month of payment, is from one dollar and fifty cents (\$1.50) to one dollar and fifty-nine cents (\$1.59) inclusive, then the royalty shall be eight

(8) cents per ton; if such market price is from one dollar and sixty cents (\$1.60) to one dollar and sixty-nine (\$1.69) per ton inclusive, such royalty shall be nine (9) cents per ton, and so on according with the schedule of royalty; but if the lessee shall have actually contracted in good faith to sell ore from said premises, then the royalty on the quantity so contracted for or sold shall be determined by the actual prices of such contracts, it being understood that each grade of ore produced shall be treated by itself, and the royalty figured thereon, and that except on ore actually sold, the royalty shall be determined by the Cleveland market price for the like kind and grades as above provided.

Price based on Cleveland delivery.—It is further understood that royalties are always to be based on Cleveland prices, whether governed by the market or by actual sale, and if the ore is to be delivered at any place other than Cleveland, the difference in freight rates, if any, shall be added to or deducted from such contract price to determine the rate of royalty.

Examining records.—The second part.. hereby agree.. that said first party shall at all reasonable times, through its officers or agents, have full and free access to the books and accounts of said second part.. in order to determine the prices at which ore mined from the leased premises has been actually and in good faith sold by the second part..

Copy of sales contract to be furnished.—Said second part.. further agree.. that each and all of.. sales contracts of said ore shall be executed in a sufficient number of original parts so that one original of every said sales contract can be furnished to the first party and that will immediately on entering into any such contract, furnish said first party with such original part.

Arbitration.—In case any dispute arises between the parties hereto, as to market price of ores prevailing at Cleveland, Ohio, at any time, or as to the good faith of any sale of ore made by said second part.., then, and in that event, all such disputes shall be left to the decision of three arbitrators, one to be chosen by each of the parties hereto on ten days written notice to the other party of its desire for such arbitration and before the expiration of said ten days, and in case of failure of either party to so choose within the time limited, then the other party shall have the right to select an arbitrator in lieu of the one so failed to be appointed by the other party, and any two arbitrators so chosen shall choose a

third, and an award of any two arbitrators so chosen (which award shall be rendered in writing within a reasonable time after their appointment) shall be final and binding upon the parties hereto.

SCHEDULE OF ROYALTIES.

Price.		Royalty.	Price.		Royalty.	Price.		Royalty.
From	To		From	To		From	To	
	\$1.49	7c	\$2.10	\$2.14	16c	\$2.55	\$2.59	25c
\$1.50	1.59	8	2.15	2.19	17	2.60	2.64	26
1.60	1.69	9	2.20	2.24	18	2.65	2.69	27
1.70	1.79	10	2.25	2.29	19	2.70	2.74	28
1.80	1.89	11	2.30	2.34	20	2.75	2.79	29
1.90	1.94	12	2.35	2.39	21	2.80	2.84	30
1.95	1.99	13	2.40	2.44	22	2.85	2.89	31
2.00	2.04	14	2.45	2.49	23	2.90	2.94	32
2.05	2.09	15	2.50	2.54	24	2.95	2.99	33

The above progression is to continue so that one cent additional royalty will be required for each additional five cents increase in price.

Seeman and Peters of Saginaw carry a number of forms of blank coal leases.

CHAPTER VII.

DEVELOPMENTS AND BORINGS.

The synoptical list of unpublished records and borings which appeared in the original report as printed in the *Michigan Miner* is here expanded by additions. The order of description is by counties, beginning at the north and west and proceeding south and east.

Missaukee County.—According to J. Smeltzer, wells down to 250 feet deep are all in unconsolidated deposits. No wells are known to penetrate rock and the extent of the coal measures is unknown.

Roscommon County.—Several authorities report coal found, e. g., T. T. Bates of Traverse City, and 4 to 10 inches of coal only 8 feet down, but on the other hand most wells down even to over 100 feet are in unconsolidated deposits, and there are no reliable reports as to the extent of the coal. The abundance of coal in the drift shows that it must occur in the bedrock near by to the north and east.

Ogemaw County.—Rose City wells down to 260 feet show only unconsolidated deposits.

At 60 feet depth coal one foot thick is said to have been reached by the drill on the farm of Wm. Hodges, T. 22 N., R. 3 E.

In the extreme southwest township Mr. U. R. Loranger has put down three holes, of which the deepest probably passed at 277 feet 6 inches down into the sandstone beneath the coal series. A strong flow of water, which is said to have 25 feet head, was encountered in No. 1. The abundance of sandstone may be taken to indicate that the hole is close to the margin of the coal series. Only the southwest corner of this county probably lies in the coal measures.

HOLE NO. 1. (George's Lake.)

All surface (Pleistocene) deposits.

S. W. $\frac{1}{4}$ of N. W. $\frac{1}{4}$, Sec. 18, T. 21 N., R. 1 E., Ogemaw county:

	Feet.	Feet.
Yellow clay	4	4
Blue clay	15	19
Sand and gravel	21	40
Sand	20	110
Gray clay, soapstone	60	170
Gravelly clay	6	175
Sand	39	214

HOLE NO. 2. (Edwards Lake.)

S. W. of N. E. of Sec. 28, T. 21 N., R. 1 E.:

	Feet.	Feet.
Sandy clay	48	48
Sand	112	160
Red clay	10	170
Red sand	85	205
Red sandrock	6	211
Fire-clay	6"	211' 6"
Red sandrock	2'	215
Blue shale	1	216
Gray rock	22	238

HOLE NO. 3. (Chapman Lake.)

N. W. of S. E. of Sec. 32, T. 21 N., R. 1 E.:

	Feet.	Feet.
Stony clay	5	5
Gray clay	30	35
Gravel	5	30
Sand	65	95
Sandy clay	50	145
Sand	20	165
Gravelly clay	15	180
Red sand	10	190
White sandrock	5	195
Gray rock	3	198
White sandrock	2'	200' 6"
Gray rock	1'	202' 6"
White sandrock	75	275
Dark gray rock	2'	277' 6"
Black shale	6"	278
Conglomerate rock (very hard)	4	282
Gray sandrock	3	285
Gray rock	20	315
Gray sandrock	3	318
Gray rock	20	315
White sandrock	23'	408' 4"

Iosco County.—Black shale is reported from several of the Tawas City wells, and has given rise to the impression that coal is in the county, but the position of the Alabaster gypsum beds, and of the Arenac county limestones, shows that these cannot be the coal measures.

The coal supposed to have been found in the Oscoda salt wells is also black shale.

Lake County.—Wells are driven down to 150 feet deep in surface deposits. There are no records of rock wells.

Oscola County.—Wells even 300 feet deep do not touch rock and the extent of the coal measures is unknown.

Coal is however found quite abundantly in the drift, especially on the Middle Branch of the Muskegon in the N. E. part of the county.*

Clare County.—Near Harrison one well 102 feet deep is said to reach bedrock, but I doubt it. Most wells, even deep ones, are in unconsolidated deposits. At Clare a well 275 feet deep stops in quicksand and has failed to reach bedrock, and on Sec. 16, T. 17 N., R. 4 W., Mr. W. H. Shepherd went 270 feet mainly through gravel and sand, with specks of coal, without reaching bedrock. The probability of good coal somewhere in this county is great. It is probably very deep.

Gladwin County.—The Gladwin City water-works put down a well by Z. T. Mason, 275 feet to rock, striking a brown sandstone about 100 feet thick, which may be the same as Winchell's upper or Woodville sandstone, one of the upper sandstones above quite a series of the coal measures. On passing through it a black shale which turned the water bitter was struck, probably a coal horizon.

A large piece of drift coal was found 12 feet down, on Sec. 3, T. 19 N., R. 2 W.

Section 25, T. 17 N., R. 2 W., four miles south of Rhodes, Estey, Calkins and Sears are said to have put down a well 300 feet by the same driller, yielding a good boiler water, which rose within 12 feet of the surface, passing through strata as follows:

85	35	Clay.
90	5	Boulders.
140	50	Hardpan and red clay.
165	25	Blue shale rock.
170	5	Coal, but as this well was put down for water, not coal, this may not be closely accurate.
300	130	Shale, sandstone, etc.

Only 50 feet away was put down a hole in May, 1899, W. E. Caster, Driller.

Estey, Mich. Hole 50 feet east of tank.

Surface clay	100	100
Hardpan	5	105
Gravel	33	137
Light slate	4	141
Dark slate	1	142
Coal	1	143
Black slate	2	145
Sandrock	9	154
Blue sand shale	11	165
Light sandrock	2	167
Dark slate	15	182
Coal	1.5	183.5
Light slate	4	187.5
Sandrock	6	193.5
Light slate	7	200.5
Dark slate	9	209.5
Sand shale	9	218.5
Black slate	10	228.5

*Bart Review, Aug. 16, 1901.

This record was furnished through W. H. Teed, Esq., and is not unlike those on Sec. 10, T. 17 N., R. 3 E. of Bay county, where we have coal with black slate above it at about 140 feet, and another at 180 to 190 feet, and down to 219 feet we are still in the coal measures.

Arenac County.—In the river at Omer (See 15, T. 19 N., R. 5 E.) coal measure sandstones with signs of vegetation are exposed in the Rifle River, and there is said to be five feet of coal 86 feet down not far from Omer, but it is doubtful. On Sec. 1 of the same township and southeast therefrom Eocarboniferous limestones like those at Bayport are well developed. Up the Rifle River beds of the coal measures are exposed at intervals and have been more or less explored. The Lingula shales are shown. See Vol. III of these reports by C. Rominger, pp. 141 to 143, for account of explorations up the river to Sec. 3 of T. 19 N., R. 4 E.

Coal is said to have been found in T. 20 N., R. 6 E., near Turner, but with no roof.

In 1875 was the great Rifle River excitement. In the Saginaw Evening News for July 23, 1898, are some interesting letters regarding the matter. The statement is made that from Clyde to Pinconning, nearly every boring encountered coal from 30 inches to 8 feet thick. This is not likely.

In 1885* a shaft was put down near Sterling to a thin coal at 50 feet depth. A small seam is also said to have been struck on the farm of Mr. Firth at 125 feet depth.

At Standish Rominger describes a well:

52	52	Drift.
79	27	Sandrock.
106	27	Blue arenaceous shales with seams of iron pyrites and narrow bands of coal.
107 ft. 1 in.	1 ft. 1 in.	Coal.
121	14	Blue shales and fire-clay.
123	2	Sandrock and
129	6	Shale, was continued down, according to Rominger passing a thicker bed of coal, to 360 feet.

There are a number of deep flowing wells, and one well put down for brine to 1,900 feet. Mr. C. Jenkins of Jackson says there is but 5½ inches of coal at 178 feet at Standish. The general thickness and character of the coal series in this part of the county appears to be like that in Bay county, but perhaps with thinner seams. A report on Arenac county is in preparation by W. M. Gregory, which we hope to make a part of Vol. IX.

*Lawton, 1886, p. 177.

Newaygo County.—According to Mr. F. Wright of Fremont, no wells have struck bedrock in this county, even though over 300 feet deep, and at Newaygo one is 335 feet deep (i. e., bedrock is less than 330 feet above tide). Coal is, however, said to be not infrequently found in the unconsolidated deposits of the drift, which indicates the near presence of coal in the Muskegon Valley. This is confirmed by the Big Rapids well. There are also reports of sandstones exposed on the northern tributaries of the Lower Muskegon, but they may be of recent formation.

Near the southeast corner of the county at Grove, a well 260 feet deep has failed to reach bedrock. It is probable that the drift is very thick all over the county.

Mecosta County.—The only well known to penetrate the bedrock in this county, and there are many 200 feet deep or more, is the Red Cross well, put down by C. S. Nims for Mr. A. L. Clark, at Big Rapids. The depth to bedrock is given as 473 (also reported 500 and 600) feet. Flows of mineral water were noted at 600, 799, 831 and 1,300 feet. The casing is now down to 900 feet, and the mineral water resembles very strongly those of Alma and Midland. It is unreliably reported that $4\frac{1}{2}$ feet of coal occurred at about 600 feet. Bottles purporting to be samples of the strata were disowned by Mr. Nims, but appear on the whole to be from coal measure rocks. The depths of the flows of mineral water and of the Marshall seem to be parallel to those at Midland.

So far as this well indicates the coal is likely to occur under both Newaygo and Mecosta counties. Some drilling up the valley of the Muskegon, toward Evart would be an interesting speculation. Some fine flows would be encountered, and probably deep drift, quite possibly also thick coal.

Isabella County.—This county is without doubt near the center of the coal basin, and the coal measure series should attain its greatest thickness. But no well has penetrated the bedrock extensively. Generally speaking, wells find plenty of water, often flowing, at a depth of 75 to 200 feet and a number of deeper wells have not struck bedrock.

At Mount Pleasant, Dr. Getchell, originally boring for water, has put down on lots 3, 4 and 6, of block 31, a number of wells with the following results:

No. 1.		
At 50 ft.		No water.
65		Water in quicksand.
To 68	3	Hardpan or rock.
73	5	Very hard rock (limestone).
79	6	Coal.
84	5	Hard rock.
85	9	Sand, etc.
100	5	Water gravel.

No. 2 at the back of the same lot was the same as No. 1 to 68 feet, then not as hard, then between 73 and 79 feet there was but little coal, and at 80 feet with one foot at the bottom.

No. 3, across the way, 70 to 80 feet deep, did not show any coal to speak of. The question as to whether this is really coal in place, which is suggested by the presence of sand and gravel under it, is pressed by the fact that at the water-works just west a well 355 feet was put down by L. J. Lincoln without reaching bedrock, and there is a new test well about half a mile south 205 feet deep, and a well of F. Prince a little east of north 300 feet deep, all of which are said to be in the unconsolidated deposits. So that while coal may be expected near Mount Pleasant and it is said to be found loose in Chippewa River, and is also reported to be only 30 feet down on Sec. 22, T. 14 N., R. 3 W., it seems likely that the Getchell wells are not in solid rock. Any farther exploration should certainly be to the east.

There has been some drilling for coal on the Upper Chippewa, by Pickand, on Sec. 28, T. 14 N., R. 5 W., said to be only 60 feet deep, and unimportant, and also at Weidman, by S. Weidmann. Reports as to results are unsatisfactory.

Bedrock is presumably very deep.

Midland County.—At Midland there are about seven deep wells to the Marshall, i. e., 1,300 feet deep, more or less. Those to the northwest reach the bedrock sooner than those to the southeast, but at Coleman, a well went through 72 feet hardpan and 204 feet of quicksand without reaching bedrock, while it is said that $2\frac{1}{2}$ miles east one reached bedrock at 280 feet. According to Z. T. Mason, the Larkin well (reported in part in Vol. V) found 6 feet of coal, just at the very top of the rock at 200 feet depth, and P. J. Reardon's mineral well is said to be 198 feet deep and just to rock. On the other hand, the wells of H. H. Dow and the Midland Chemical Company go 285 feet to 300 feet to the rock, and the following record, which shows no coal, is an example of them:

285	285	Pleistocene.	Surface deposits.
318	23	Coal Measures.	Micaceous white sandstone, fresh water.
345	27		Black soft shale.
420	65		Sandstone, brine at 420.
455	35		Hard shale.
525	70		Sandstone.
575	50		Hard shale.
582	7		Hard sandstone.
700	118		Black shale.
745	45		Calcareous (Fe CO ₂) shale.
810	65		Black shale.
		Parma.	
920	110		White sandstone.
		Grand Rapids.	
970	50		Argillaceous limestone.
1050	80		Plaster bed, fairly pure anhydrite.
1130	80		Calcareous shale.
1205	75		Limestone.
1305	100	Marshall.	White sandstone somewhat ferruginous.

The black shales in above record may correspond to coal horizons nearer the margin of the basin.

Near Smith's Crossing, however, only four miles away, a coal field is just being developed, of which the following record may give an idea. It seems probable that these coals are the same as that of the Wolverine Coal Co. in Bay county (T. 14 N., R. 3 E.), and that they belong to the Verne coals.

Smith's Crossing, Midland Twp., Section 35 (Northeast quarter), T. 14 N., R. 2 E., elevation about 620 feet A. T.

Farm of Dougald Currie.

Clay	20 ft	20 ft
Sand	10	30
Clay	18	45
Quicksand	12	58
Clay	44	102
Sandrock	18	120
White rock	0 ft 10 in	120 ft 10 in
Red rock	2	122 10
White rock	2	124 10
Red rock	8	132 10
White rock	35	167 10
Coal	1	168 10
White rock	2 ft 6 in	171 ft 4 in
Coal	3 6	174 10
White rock	10	184 10
Sandrock, partly slate rock	10	194 10
White rock	21 11	205 9

A small vein of water passed through yielded a tablespoonful to a cup of salt (16 tablespoons to a cup), i. e., 5 to 10% of salts.

If the Smith Crossing coals at 168 to 174 feet are the main coal seam of the Bay county field, the Verne coals, then it is probable that the coal at 200 feet or so around Midland corresponds to the same horizon, which is probably equally deep near the Amelith shaft, so that the rest of the strata shown in the Midland section are additions to the base of the coal measures.

Further tests are said to show that the "coal" is slaty.

At Barnes', about 7 miles west, in T. 14 N., R. 1 E., rock is said

to have been struck at 206 feet, with considerable coal above it up to 171 feet.

Near Sanford, T. 15 N., R. 1 W., was the old State salt well which is referred to in the Michigan Legislative documents, between 1840 and 1842, which was to have been 300 feet deep, but was really but 100 to 200, I understand.

In the same township were two borings by J. Russell, as follows:

On Sec. 4, T. 15 N., R. 1 W., June 3d, 1895.

Sand	16 ft	
Blue clay	21	37 ft
Quicksand	4	41
Clay, hard	25	66
Hardpan and gravel	37	103
Boulders	12	115
Clay and gravel	18	133
Boulders	10	143
Red clay	33	176
Sand and gravel	6	182
Sand and slate rock	5	187
Brown slate	4	191
Red sandrock	5	196
Sand and slate mixed	5	201
Water sandrock	47	248
Sandy fire-clay	4	253

On Sec. 27, T. 15 N., R. 1 W., April 22d, 1895.

Sand	7 ft		
Reddish clay	9		16 ft
Blue clay	3		19
Quicksand	2		21
Blue clay, hard	20		41
Sand	4		45
Hardpan and gravel	12		57
Very hard blue stone	—		—
Gravelly hardpan	17		74
Soft red clay	6		80
Sand and gravelly hardpan	37		117
Red clay	17		134
Alabaster or white rock	5 ft	6 in	139 ft 6 in
Red clay	24	6	164
Loose sandrock	1		165
Red clay	13		178
Red sandrock	18		196
Soap or soft slate	5		201
Hard slate	3		204
Sandy fire-clay	15		219
Dark slate	9	10	228 10
Poor coal	—	2	229
Rotten black slate	1		230
Light slate	8	6	233 6
Hard dark rock	1	6	235
Light slate	5		240
Water sandrock	14	1	254 1

Northeast of Midland, near Hubbard, explorations have been made for coal on Sections 24 and 25, T. 15 N., R. 2 E. The figures given me do not check exactly, but are about as follows:

Well No. 1, by J. Coreyell, for Midland business men, on McDonald farm, S. $\frac{1}{2}$ of S. W. $\frac{1}{4}$, Sec. 24, T. 15 N., R. 2 E.

Sand	5 ft 6 in		
Light clay	77	82 ft 6 in	
Blue clay	5	87	6
Gravel	6	93	6
Hardpan	97	190	6
Gravel	2	192	6
Hardpan	48	240	6
Gravel	1	241	6
Hardpan	8	249	6
Black slate	4	253	6
Slate	14	267	6
Coal	0 11	268	5

Well No. 2, on the Waldo farm (100 N., 800 W.), W. $\frac{1}{2}$ of S. E. $\frac{1}{4}$,
Sec. 25, T. 15 N., R. 2 E.:

Light clay	78 ft		
Hardpan	24	102 ft	
Sand	15	117	
Hardpan	5	122	
Blue clay	40	162	
Hardpan	7	169	
Sand and gravel	22	191	
Hardpan	4	195	
Sand and gravel	5	200	
Slate	25	225	
Coal	2 ft 8 in	227 ft 8 in	
Fire-clay and blue clay	11	238	8

Well No. 3, on Chas. Knorr farm (300 N., 400 W.), S. E. of S. E.
of Sec. 25, T. 15 N., R. 2 E.:

Clay	80 ft	80 ft
Hardpan	22	102
Gravel	1	103
Hardpan	34	137
Gravel	2	139
Blue clay	15	154
Hardpan	10	164
Sand and gravel, with water	6	170
Hardpan	4	174
Quicksand	4	178
Sand and gravel	4	182
Hardpan	2	184
Sand, gravel and boulder	4	188
Hardpan	2	186
Sandstone	2	188
Sand and gravel	10	198
Hardpan	3	201

Well No. 4, Waldo farm (500 N., 1200 W.), S. W. $\frac{1}{2}$ of Sec. 25,
T. 15 N., R. 2 E.:

Clay	84 ft	84 ft
Hardpan	51	135
Sand	25	160
Gravel	8	168
Blue clay	10	178
Sand and gravel	12	190
Hardpan	8	198
Slate	40	238
Coal	1 ft 6 in	239 ft 6 in

Well No. 5, on Gerstacher farm (1000 N., 1500 W.), S. $\frac{1}{4}$ of N. W.
 $\frac{1}{4}$ of Sec. 25, T. 15 N., R. 2 E.:

Clay	88 ft	88 ft
Sand	2	90
Hardpan	94	134
Blue clay	10	134
Sand	5	139
Hardpan	63	202
Gravel, very coarse	6	208
Sand and gravel	6	214
Hardpan	10	224
Sand and gravel	6	230
Hardpan	4	234
Slate	38	272
Coal	2 ft 3 in	274 ft 3 in

These holes were put down by J. Coreyell, for a syndicate of Midland business men, and show about 200 feet of drift. The upper 70 or 80 feet are always of solid clay, probably lake clays which were deposited beneath the waters of the former great lake system, and will be found all over the Saginaw Valley. About 200 feet of drift seems to be the prevalent thickness in this region, outside of the valleys in the bedrock. There is a bed of coal two feet or less thick, at a depth of 230 to 240 feet. It seems quite likely that this is one of the Verne coals, at the same horizon as the 140 foot coal at Monitor, Bay county, for the country is probably higher and the indications are that the strata get deeper to the north and west around here. One hole went 257 feet and was still in drift.

Evidently the coal seams of Bay county extend into Midland county.

Bay County.—Coal probably underlies all of this county, but there is a brown sandstone which appears at the top of the series which I suspect lies in valleys and troughs cut out of the coal. For instance, Mr. Z. T. Mason reports the following well in Garfield township, $5\frac{1}{2}$ miles due west from Lengsville, Sec. 26, T. 16 N., R. 3 E.

At top muck, then to 80 feet clay, beneath it stones and gravel, level of Linwood flows, then fire-clay and hardpan, 135 feet to bedrock; thence to 300 feet mainly brown sandstone, with a really soft water rising to within 5 feet of the surface. Contrasting this with neighboring wells, it seems likely that the sandstone cuts out and replaces part of the coal series. Other wells show a varied succession of beds, with a number of coal horizons; for instance, the following wells of Mr. Mansfield, on Sec. 10, T. 17 N., R. 3 E., and old borings by Mr. Holcroft on Sections 28 and 34 of the same township, which like wells at Estey in Gladwin county show coal horizons at about 140 feet and 180 feet and give promising successions of beds for the first two hundred feet or more.



TIPPLE OF MICHIGAN COAL CO., SAINT CHARLES.



TIPPLE OF VALLEY COAL CO., BAY CITY.

There are a very large number of coal records in this county which will be used in preparation of a county report. They are too many to include here, and some are not for publication yet. This remark applies also to Saginaw county.

The general record of the Bay City salt wells is given in Vol. V, but there is considerable variation in the depth of the Marshall, due to its undulations. Wells to rock run 80 to 90 feet deep.

Land of J. Mansfield, Sec. 10, T. 17 N., R. 3 E., S. E. $\frac{1}{4}$.

No. 2 is 1 foot higher than No. 1

No. 3 is 9 feet higher than No. 1.

NO. 1.		
Clay	80	80
Sand	4	84
Hardpan	8	92
Black shale	2	94
Blue shale	20	114
Gray shale	18	132
Black shale	2	134
Coal	6"	134½
Blue shale	15'	150
Gray shale	10	160
Sandrock	5	165
Coal	5"	165' 5"
Black shale	9'	174' 11"
Coal	6"	175' 5"
Blue shale	10	185' 5"
NO. 2.		
Clay	82	82
Hardpan	9	91
Black shale	1' 6"	92' 6"
Blue shale	15	107' 6"
Hardpan	15'	122'
Sandrock	8	131
Hardpan	10	141
Sandrock	40' 6"	181' 6"
Coal	11½"	192' 5½"
Sandrock	14	206' 5½"
Blue shale	2	208' 5½"
Sandrock	6"	208' 11½"
Coal	2"	209' 1½"
Blue shale	3	212' 1½"
Sandrock	6	218' 1½"
Blue shale	1	219' 1½"
Sandrock		
NO. 3.		
Clay	36	36
Gravel	1	37
Red gravel	1	38
Clay	52	90
Black shale	2	92
Hardpan	4	96
Black shale	3	99
Slate rock	4	103
White shale	3	106
Blue shale	21	127
Black shale	2' 9"	129' 9"
Coal	8"	130' 5"
Blue shale	25' 7"	156
Sandrock	24	180
Coal	3"	180' 3"
Sandrock	5	185' 3"

Porter borings, Sec. 34, T. 17 N., R. 3 E., about 100 feet west of the center line and 5 feet north of the Pinconning and Glencoe logging R. R. track:

No. 1.		
Sand	6	6
"Clay containing gravel stones, coarse gravelly clay," i. e., till, "hard to drill, dried specimens looked like arenaceous fire-clay....."	102	108
Hard arenaceous fire-clay, sand predominating	13	121
Argillaceous sandrock	1	122
Light blue shale	(13' 6"?)	136' 6"
Coal	1' 1"	137' 7"
Arenaceous fire-clay	8' 11"	146' 6"

NO. 2.

(Sec. 28 or 33, T. 17 N., R. 3 E.?) about a mile west farther up the road:

Soil	8"	8"
Sand, ochrish colored	7' 4"	8'
Clay, stiff gray and hard when dry.....	42	50
Clay, occasional blue streaks.....	11	61
Clay, fine grained, gray and hard when dry..	26	87
Clay, fine grained, pinkish when wet.....	1	88
Clay, light blue	6	94
Clay, brown hard	6	100
Clay, bluish, a little sandy	7	107
Sandrock, $\frac{1}{2}$ argillaceous	6	113
Shale, a piece of coal came up at about 114 feet depth	2' 6"	115' 6"
Breccia, hard, sand, clay and gravel cemented, ground runs between this and next, as is supposed	4' 11"	120' 5"
Shale, a layer of coal embedded in this shale about 2" thick and about 7" from the bottom.		
Tubing about 6 $\frac{1}{2}$ ' from bottom.....	27	147' 5"

When we come to the southern part of the county it has been pretty thoroughly bored up for the first one or two hundred feet. We have between two and three hundred records, and there are, of course, a great many which we do not have. Many, perhaps most, of the records go only so far as to develop the upper or Verne coals, which are usually between 110 feet and 150 feet down and are shown in the sections of Plate IX. These seem to be comparatively level and persistent, and easier to trace, independent of the fact that we have many more holes through them. But there are some holes which help to show the lower measures as well. For instance, the following record, by Goff Paul, 1,000 paces north, 15 paces west, in Section 3 of Bangor, Township 14 N., R 5 E.:



AIR COAL CUTTING MACHINE, WENONA MINE.

1. The first part of the document is a list of names and addresses of the members of the committee.

2. The second part of the document is a list of names and addresses of the members of the committee.

3. The third part of the document is a list of names and addresses of the members of the committee.

4. The fourth part of the document is a list of names and addresses of the members of the committee.

5. The fifth part of the document is a list of names and addresses of the members of the committee.

6. The sixth part of the document is a list of names and addresses of the members of the committee.

7. The seventh part of the document is a list of names and addresses of the members of the committee.

8. The eighth part of the document is a list of names and addresses of the members of the committee.

9. The ninth part of the document is a list of names and addresses of the members of the committee.

10. The tenth part of the document is a list of names and addresses of the members of the committee.

11. The eleventh part of the document is a list of names and addresses of the members of the committee.

12. The twelfth part of the document is a list of names and addresses of the members of the committee.

13. The thirteenth part of the document is a list of names and addresses of the members of the committee.

14. The fourteenth part of the document is a list of names and addresses of the members of the committee.

15. The fifteenth part of the document is a list of names and addresses of the members of the committee.

16. The sixteenth part of the document is a list of names and addresses of the members of the committee.

17. The seventeenth part of the document is a list of names and addresses of the members of the committee.

18. The eighteenth part of the document is a list of names and addresses of the members of the committee.

19. The nineteenth part of the document is a list of names and addresses of the members of the committee.

20. The twentieth part of the document is a list of names and addresses of the members of the committee.

21. The twenty-first part of the document is a list of names and addresses of the members of the committee.

22. The twenty-second part of the document is a list of names and addresses of the members of the committee.

23. The twenty-third part of the document is a list of names and addresses of the members of the committee.

24. The twenty-fourth part of the document is a list of names and addresses of the members of the committee.

25. The twenty-fifth part of the document is a list of names and addresses of the members of the committee.

26. The twenty-sixth part of the document is a list of names and addresses of the members of the committee.

27. The twenty-seventh part of the document is a list of names and addresses of the members of the committee.

28. The twenty-eighth part of the document is a list of names and addresses of the members of the committee.

29. The twenty-ninth part of the document is a list of names and addresses of the members of the committee.

30. The thirtieth part of the document is a list of names and addresses of the members of the committee.

Sand	11	0
Clay	71	82
Hardpan (till)	3	85
Quicksand and gravel	5	90
Quicksand and fire gravel.....	70	160
Slate	9	169
Hard rock	6'	175' 3"
Black slate	11'	186' 10"
Coal D. (middle rider).....	2'	188' 11"
Fire-clay	27	215' 11"
Slate with streaks of hardrock, i. e., in part probably nodules of siderite.....	60' 4"	276' 3"
Black slate (C').....	11	287' 3"
Hard rock	3	290' 3"
Black slate	4	294' 3"
Coal C. (Saginaw seam).....	1'	295' 5"
Fire-clay	30	325' 5"
Hard rock	2	327' 5"
Slate	20	347' 5"
Black slate	7	354' 5"
Coal (Lower rider)	0'	355'
Fire-clay	18'	373' 7"
Hard rock (limestone?).....	4'	377' 3"
Slate	22	400' 3"
Black slate	13	413' 3"
Coal (Lower coal)	1'	415
Fire-clay	27	442
Eocarboniferous:		
Hard rock	23	465

According to reports through Shearer Bros., the Saginaw seam, coal C of the above record, is in places thick enough to work (4½ feet), in this region.

The "hard rock" is probably mainly limestone, but sometimes perhaps nodules of siderite, pyrite, or indurated sandstone. I think that at 442 feet the Eocarboniferous formation is reached. According to Rominger's report the Parma sandstone is not marked at Kawkawlin, but gypsum was encountered at 400 feet. If such is the case, we may infer that the floor of the coal measures rises from the old Bay City city well (Plate VI of Vol. V) to the north, and so 442 feet of the boring just cited may correspond to 565 feet of that. I understand that it is true also in following the salt rock down the river toward Essexville that it rises. The deep wells around Munger (that by Moses Thrash, for instance) show a heavy sandstone containing a very salt brine at varying depths from 348 to 265 feet down, which I take to be the base of the coal measures, in which case we may infer that the basement on which the coal measures rests rises in that direction also.

Not far away, on Section 36, a hole bored for N. P. Bradley with the Bullock diamond core drill gave the following record,* in which the base of the coal measures seems to come in at about 367 feet,

*Which I owe to the courtesy of the owner and the Sullivan machine Co., of Chicago.

and there are unusually many coals in the lower part of the series and the Verne coals appear to be absent.

Record of hole for N. B. Bradley with Bullock diamond core drill (3 inch) near Bay City, Mich.

(Sec. 36?, T. 14 N., R. 6 E., near headwaters of Quannecussee.)

Date, 1889.	Time worked. Hours.	Formations.	Amount drilled.	Core saved.
June 7 to 13.....	10	Driving casing (Boulder core).....	80'	4' 6"
June 15.....	10	Drilling and churning.....	5' 88'	1'
June 17.....	10	Drilling and churning.....	3' 88'	2'
June 18.....	10	Drilling with bit.....	17' 105'	10'
June 19.....	10	Drilling with bit.....	15' 120'	11'
June 20.....	10	Drilling—pipe.....	10' 130'	8'
June 21.....	10	Dark shale.....	10' 140'	8'
		Light shale.....	3' 143'	2'
June 22.....	10	Sandstone.....	12' 155'	10'
		Dark shale.....	3' 158'	2'
		Sandstone.....	3' 161'	2'
June 24.....	10	Sand and shale.....	12' 173'	10'
June 25.....	10	Sandstone.....	6' 179'	4'
		Black shale.....	4' 183'	2'
		Gray shale rock.....	8' 191'	7'
June 26.....	10	Gray shale rock.....	4' 195'	3'
		Black shale.....	4' 199'	3'
		Black shale and sand.....	9' 208'	8'
		Drove 7' 4" pipe.....		
June 27.....	10	Black shale and sandstone.....	7' 215'	6' 6"
		Sandstone.....	2' 217'	2'
June 28.....	10	Sandstone mixed.....	13' 230'	12' 6"
June 29.....	10	Black shale and fire-clay.....	7' 237'	6'
July 1.....	10	Black shale.....	3' 240'	
		Fire-clay.....	3' 243'	13'
		Sand and shale.....	5' 248'	
		Dark shale.....	2' 250'	
July 2.....	10	Dark shale.....	6' 256'	
		Coal.....	1' 257'	
		Sand white mixed.....	4' 261'	
		Fire-clay.....	5' 266'	16'
July 3.....	10	Dark shale.....	18' 284'	18'
July 4.....	10	Dark shale.....	8' 292'	
		Coal.....	1' 293'	
		Dark shale.....	2' 295'	
		Sandstone.....	8' 303'	19'
July 5.....	10	Fire-clay and shale.....	4' 307'	
		Coal.....	6' 308'	4"
		Sand and shale.....	6' 314'	
July 6.....	10	Black shale.....	5' 319'	11'
		Black shale and clay.....	4' 323'	
July 8.....	10	Black jack.....	3' 326'	
		Coal.....	6' 327'	
		Soft white clay.....	5' 332'	8'
July 9.....	10	Black shale.....	10' 342'	
July 10.....	10	Sand and shale mixed.....	3' 345'	12'
July 11.....	10	Dark shale.....	11' 356'	10'
		Black jack.....	3' 359'	
		Coal.....	1' 360'	
		White sandstone.....	3' 363'	
July 13.....	10	Blue shale and sand.....	3' 366'	2'
		TOP OF PARMA?		
		Iron pyrites.....	1' 367'	
		Blue sand with grit.....	6' 373'	9'
July 15.....	10	Sand.....	13' 386'	10'
July 16.....	10	Sandstone pins.....	20' 406'	12'
July 17.....	10	Same.....	20' 426'	12'
July 18.....	10	Hard quartz.....	23' 449'	16'
July 19 and 20.....	10	Setting bit and replacing rods.....		
July 22.....	10	Sandstone.....	10' 459'	7'
July 23 and 24.....	10	Sandstone.....	4' 463'	3'
July 26.....	10	Repairing pump.....		
July 27.....	10	Sandstone.....	10' 473'	9'
July 29.....	10	Lime and quartz.....	10' 483'	9'
July 30.....	10	Same.....	12' 495'	11'

The four coals of the report just given from Mr. Goff Paul on Section 3, Bangor Township, may be traced more or less continuously in Sec. 3, 4 and 10, rising to the south until the lower coal is only about 304 feet down. The lower rider (which here is the thicker seam) is only a few (six) feet above. At the center of Section 10 the base of the coal measures appears to be but 267 feet down, but in general it is near 400 feet down. These records do not show the Verne coals and their rider, and the records must be supplemented (p. 106) by those of the Handy Bros. and Wenona mine, which are less than a mile away.

In Section 19 another deep boring, not far from the Central and Michigan Mines on Sec. 25, enables us to see something of the lower formation here, to-wit:

Well of Peter Miller, W. $\frac{1}{2}$ of N. E. $\frac{1}{4}$, Sec. 19.

Clay	81	81
Blue slate	29	110
Hard, sandy lime rock	7	117
Dark slate	20	137
Coal (Lower Verne)	2' 4"	139' 4"
Fire-clay	9	148' 4"
Slate	23	171' 4"
Hard rock	3' 2"	174' 6"
Dark slate	37' 8"	212' 2"
Black slate	5' 9"	217' 11"
Coal (Saginaw seam?)	2' 10"	220' 9"
Fire-clay	3' 2"	223' 11"
Blue slate	27	250' 11"
Light slate	19	269' 11"
Hard rock	3' 7"	273' 6"
Dark slate	21	294' 6"
Black slate	4' 5"	298' 11"
Coal (Lower seam)	1' 2"	300' 1"
Black slate	2' 1"	302' 2"
Fire-clay	4' 9"	306' 11"
Hard sandrock	25'	332' 11"

From this it is but little over a mile to the mines on Sec. 25 of the Central and the Michigan Mining Co. Thence southwest we can, through records furnished by the kindness of Mr. U. R. Loranger, trace the Verne coals quite continuously to the shaft of the Valley Coal Co. and the Amelith Shaft of the Pittsburg Coal Co., and thence to the Bay No. 1 and No. 2, the Monitor and Wolverine mines. The borings are, however, deep enough only to show the undulations and splits of the Verne group of coals, which sometimes split into three or four thin seams, and are usually from 110 to 190 feet down, 130 to 140 feet being common figures. (See Plate IX.)

The base of the coal series still appears to be not far from 400 feet down, say 388 to 444 feet, so that we appear to be still on the marginal shelf, Fig. 1, which borders the southeast side of the basin.

Huron County.—The coal in Huron county is practically confined to Sebewaing township. (See Fig. 9.) Streaks of coal and coal fossils are found elsewhere, as in the grindstone quarries, but there is no probability of finding coal, even though four feet of coal is said to have been found on the farm of James Chesney at 65 feet depth. The neighborhood of Sebewaing has been very thoroughly bored, and many wells have gone far beneath the coal to the Marshall sandstone to get flows. For detailed records see Vol. VII, Part II, p. 143 and following pages of the Huron county report, and also the column on p. 86 of Water Supply paper No. 31. The J. C. Likens Coal Co. has been recently organized, and is said to strike four feet of coal at 103 feet. There are but 40 to 60 feet of surface deposits immediately beneath Sebewaing, mainly lake clays, and two coal seams are found in the first 120 feet, though the lower one is not usually over 80 to 90 feet deep. The natural dip of the coal measures brings them to the rock surface a mile or two north and northeast of Sebewaing, while south and southeast they are cut out by a river channel which is filled with 150 feet or more of drift, and runs through Sections 15, 21, 20, 29, 31, T. 15 N., R. 9 E. The following record is as full and complete as any, but is only 30 feet from a well in which no coal was recorded:

J. C. Liken well, Sec. 18, Sebewaing. N. E. $\frac{1}{4}$ Sec. 18, T. 15 N., R. 9 E., May 19th, 1896.

Surface.....	51	51
Pleistocene.....		
Clay.....	1	52
Sand and gravel.....	2	54
Loose sandrock.....	2	56
Coal measures.....		
Hard rock.....	18'	74'
Dark sandrock.....	8"	74' 8"
Coal about.....	1' 6"	76'
Sandrock.....	6'	82'
Slate.....	3' 8"	85' 8"
Bottom slate.....	1' 4"	87'
Parma.....		
Sandrock.....	13	100
Grand Rapids.....		
Light slate or sandy fire-clay.....	96	196
Hard dark rock.....	24	220
Slate.....	20	240
Hard lime rock.....	8	248
Napoleon, i. e. Upper Marshall.....		
Sandrock.....	55	303

Montcalm County.—The coal measures probably underlie the whole of this county, but we have absolutely no definite information concerning them. Coal has been reported, but under conditions that render it probable that it was in the surface deposits, in T. 10 N., R. 8 W., and at Amble, T. 12 N., R. 9 W., on the farm of

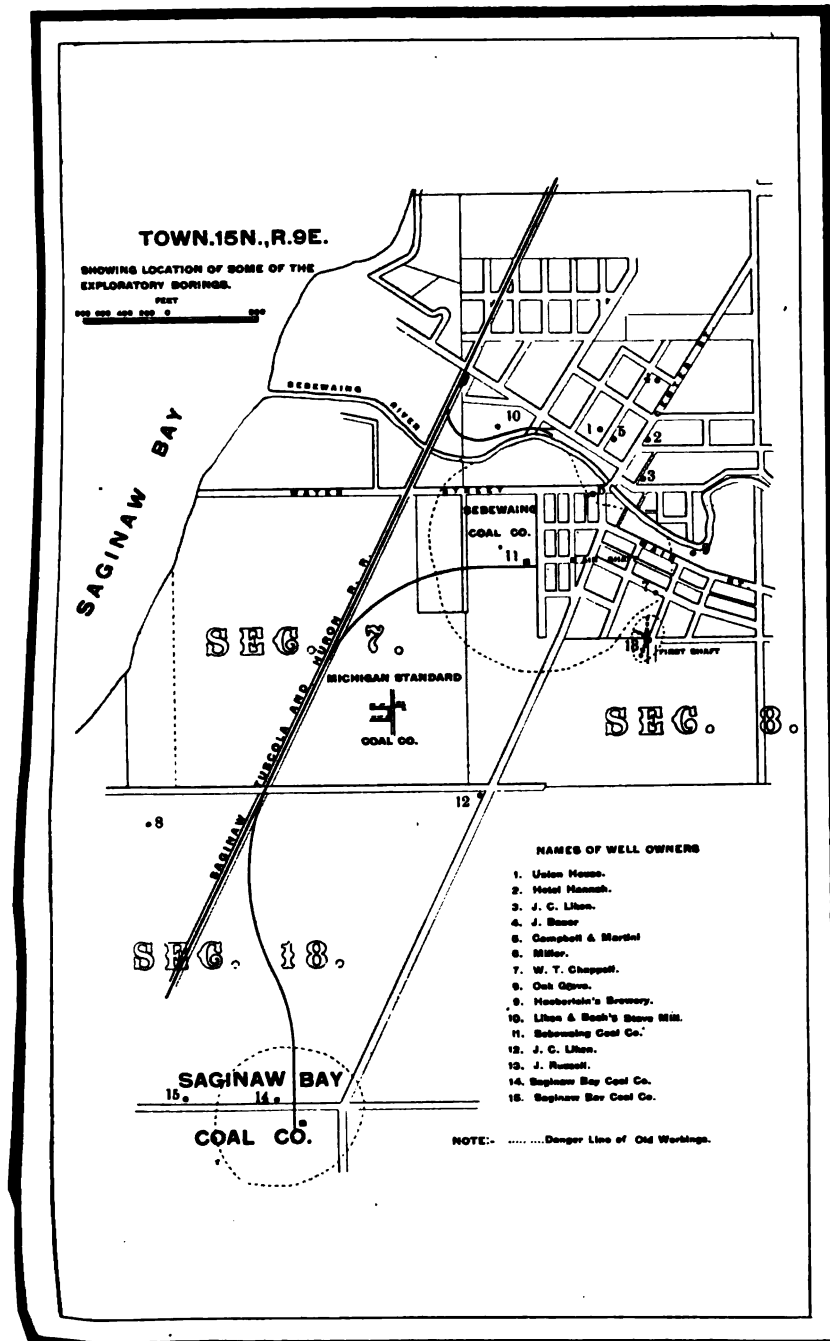


Fig. 9. Sketch map of Sebowaing coal region, Town. 15 N., R. 9 E., showing location of some of the exploratory borings.

N. Olsen, for the well was put down 360 feet by C. A. Denton, the driller, without reaching bedrock. Another well on Sec. 11, T. 11 N., R. 10 W., three-quarters of a mile S. E. of Maple Hill, 320 feet deep did not reach bedrock.

Gratiot County.—The drift seems to lie deep but irregularly over the northern part, as though heavily cut up by river valleys. For instance, it is but 335 feet to rock at the Harrington House, St. Louis, while at Alma it is 500 feet. The record of the old St. Louis magnetic well, which only went through drift, is given by Winchell in detail (Am. Ass. for the Adv. of Sci., 1875, B. p. 31). The new Harrington House well has three casings and can yield three waters, the first an 8-inch, stopping at 100 feet in a nest of boulders; the second 6-inch, stopping at the level of the magnetic mineral water well at 255 feet in a nest of boulders with lots of water. Then there is a 4-inch pipe to 335 feet, the bedrock, which is red sandstone. Thence it is mainly white sandstone down to 599 feet, when they entered a white shale and stopped. The old St. Louis salt well, 1,314 feet deep, put down by Hardenburgh and Sager, was almost the same—surface deposits 337 feet, then 200 feet mainly sandstone.

Some thin coal has been found around Ashley at about 170 feet to 190 feet and deeper, but the bedrock surface here to is very irregular, from 50 feet dropping to over 200 feet in a mile or two north.

The Ithaca well has been given in p. 63, Vol. V. Several additional similar wells have been put down since.

On the farm of M. White at North Star coal is reported at 205 feet, and at 296 feet two miles east of Ithaca, on Wm. Dusch's farm, but bedrock was struck only a short distance above, at 292 feet.

The Alma well (Sec. 34, T. 14 N., R. 3 W., about 755 A. T.) is represented by a fairly full set of samples and an abstract of the record, summarized from that preserved by Prof. C. A. Davis, is as follows:

ALMA WELL.

Pleistocene.		
Clay and gravel with quicksand and water at 60 feet and 3 feet gravel at 187 feet.....	475'	475'
Sand and gravel.....	25'	500'
Woodville?		
Feldspathic sandstone (335-590 at St. Louis).....	50'	550'
Coal measures.		
Pyritiferous black shale, coal horizon.....	25'	575'
Blue shale.....	40'	615'
White shale.....	22'	637'
Pebbly sandstone.....	38'	675'
Shale sometimes black, coal reported.....	35'	710'
Parma.		
Pyritic sandstone.....	80'	790'
Grand Rapids.		
Blue and black sandy shales.....	70'	860'
Blue and white gypsum.....	35'	895'
Bituminous, dolomitic red or blue or argillaceous		
limestones (cement rock or hydraulic).....	120'	1015'
U. Marshall or Napoleon.		
Clean white sandstone.....	85'	1100'
L. Marshall.		
Red sandy shale.....	200'	1300'
Blue shale.....	20'	1320'
Red shales.....	200'	1500'
Coldwater.		
Blue shales.....	75'	1575'
Fine grained grit, no water.....	200'	1800'
Dark shales.....	70'	1875'
Blue shales, somewhat sandy down to 2,000 ft.....	595'	2250'
Berea Shale.		
Black shale.....	25'	2300'
Devonian.		
Blue shales.....	60'	2360'
Ohio Shale.		
Black shale.....	260'	2620'
Black shale with harder streaks.....	130'	2750'
Traverse.		
Dolomitic limestone.....	30'	2780'
Blue shale.....	20'	2800'
Sandy limestone, dolomitic.....	61'	2861'

Saginaw County.—So much boring has been done here that we can give but a few sample records. The deepest well of which samples are preserved is one put down February 10, 1862, by the Ann Arbor and Saginaw R. R. Co., at (Salina) South Saginaw, probably on the east side of Saginaw River, a little south of the center of Sec. 35, T. 12 N., R. 4 E., somewhere near where the F. & P. M. Belt Line bridge is. Corresponding horizons are about 50 feet deeper than at the old first well, as recorded by Dr. Lathrop. It is noteworthy that in neither of these wells does the gypsum bed which we find at Bay City, Midland and Alma occur, and the interval from Parma to Marshall is less. We may give the record of the Salina well briefly as follows:

*See also Water Supply Paper of the U. S. Geol. Sur., No. 21, Fig. 2.

Pleistocene.		
Surface deposits.....	90'	90'
Yellow limestone.....	30'	120'
Blue calcareous shale.....	115'	235'
Marly limestone.....	70'	305'
Bituminous black shales (coal horizon).....	18'	318'
Green shale.....	22'	340'
Parma?		
White sandstone.....	145'	485'
Black shale.....	8'	493'
Unconformity?		
Grand Rapids.		
Arenaceous limestone.....	32'	525'
Impure sandstone.....	20'	545'
Calcareous green shale.....	25'	570'
Green shale.....	95'	665'
Argillaceous dolomite.....	25'	690'
U. Marshall or Napoleon.		
Leaves off in clean sandstone.....	25'	715'

We have also a detailed diagram of a salt well drilled by F. H. Mason, Bay City, for Gov. A. T. Bliss, Saginaw, at Carrollton Mill, drawn by A. C. McKinnon, Bay City.

5	5	Sand.
95	90	Blue clay.
120	25	Hardpan.
		6 in. pipe to here.
150	30	Limerock.
190	40	Sandy shale.
230	100	Sandrock.
300	10	Black shale.
375	75	Blue shale. Unconformity?
400	25	Sandy lime. Upper salt rock or Parma? Somewhere here there was a cavity where the drill dropped.
430	30	Sandrock.
480	50	Sandy shale.
540	60	Blue shale.
570	30	Sandy lime.
590	20	Blue shale.
592	2	Sandrock, 5½ inch hole to here, where they probably shut off the gypsum.
625	33	Blue shale.
650	25	Limerock, very hard.
750	100	Sandrock, known as salt rock, that brine flows through; 4 in. hole to bottom. Napoleon sandrock.

There appears to be a dip of some 40 feet in the Eocarboniferous strata from Carrollton to South Saginaw, but the salt wells are deeper at Zilwaukee and deeper yet at Bay City. Thus we must have passed over an upward flexure in the Eocarboniferous, the top of which probably crosses the river on Sec. 24, T. 12 N., R. 4 E., near the Wylie Bros. wells.

The wells of the Brewer Lumber Co. and those at Mershon are but little over 700 feet deep, and the saline at the Germain factory, near the west ¼ post of Sec. 29, T. 12 N., R. 5 E., on ground nearly 20 feet higher, is said to be but 750 feet deep.

Below 398 feet in the First or Potter well, or 375 feet in the Bliss well, and 525 feet in the South Saginaw well, we are clearly in the Grand Rapids,—Eocarboniferous.

On the other hand, passing to the southeast, we find the South Saginaw wells deeper, 820 feet, and at Garfield and at St. Charles,

as we have previously stated (p. 38) the Napoleon sandstone and the base of the coal measures are somewhat lower than at Saginaw. There is probably, therefore, something of an extra rise at Saginaw, of the Eocarboniferous strata, beside a general pitch to the northwest. To the southeast, toward Bridgeport, the Napoleon seems to rise but slowly, while the coal measures, judging from the wells of Hon. Henry M. Youmans, are at least 200 feet thick.

At Blackmar the Napoleon appears to be between 360 and 450 feet down, but there is no indication of the Michigan series above, or at any rate no line was drawn between it and the coal measures. Moreover, Mr. Higgins' explorations found on Herpel's farm, about four miles away, near the center of Section 7, T. 10 N., R. 5 E., at least 200 feet of coal measures, as follows:

Test hole No. 6.			
Surface	64 ft.	6 in.	64 ft. 6 in.
Sandrock, which replaces a coal at 67 feet	28	6	93
Black shale	26	6	93
Gray shale	23	6	120
Sandrock	1		143
Gray shale	1		144
Coal	1	6	144
Fire-clay	8		145
Light gray shale	5	6	153
Dark gray shale	15		159
Sandrock	11		174
Gray shale			185
Coal	6	2	185
White shale	7		191
Black shale	4		198
White rock (hard, probably limestone)....	5		202
Sandrock			207

Also Mr. With's well in Tuscola county (which see), on the same general strike line, shows at least 279 feet of coal measures. Apparently, therefore, the Michigan series has really dropped out and the unconformity at the base of the coal series to which we have called attention is well marked. We cannot, therefore, use the stratigraphy of the Eocarboniferous "salt rocks" as a guide to our coal correlations, and since some of the lower coals may be more irregularly laid down upon this eroded surface than the upper, as indeed they are said to be in Indiana, Iowa and similar States, it will be well to begin our correlations at the top.

The coals which occur near the surface around Munger, as may be seen from the table and correlation with the deep holes south of the Wenona and Handy Bros. Mines (Plate IX), appear to correspond to the Verne coals.

Section near Munger Station, 594 A. T.:

O. W. Blodgett's general section.	Blodgett's deepest, back of store.	Moses Thrash.
Quicksand.....16' to 18'	Surface.....89' 89'	Clay.....73'
Clay, blue or red solid.....70' to 90'	Shale.....48' 135'	Conglomerate.....28' 101'
Gravel.....6' to 8'	Sandrock.....2' 137'	Slate.....32' 133'
Hardpan.....2'	Shale.....2' 6" 139' 6"	Sandstone and slate.....22' 155'
Bedrock at about.. 98'	Slate.....1' 6" 141'	Whitish yellow shale.....22' 177'
2 miles east of Mun- ger 3¼ feet of coal with no roof.	Black slate.....1' 1" 142' 1"	
Coal indications at (F).....142'	Coal F.....1' 9" 143' 10"	"Graphite" i.e. soft black shale.....10' 187'
Sandy fire-clay.....10'	Fire-clay.....158' 8"	Coal and slate D.....9' 196'
Coal at (E).....155'	Coal E.....1' 5" 160' 1"	Hard conglomerate.....37' 233'
Sandrock 6' to 1' coal at.....175'	Fire-clay, light, no grit.....161'	Coal and black slate C.....15' 248'
Fire-clay (D).....	Salty sandrock.....58' 219'	Sandrock.....3' 251'
Dark sandrock with salt water, at about.....180'	Bl'k sandy shale.....31' 250'	Whitish slate.....54' 306'
for.....40' to 50'	Dark sandrock.....10' 250'	Blue slate.....25' 330'
Shale.....8' to 10'	Sandy shale.....5' 255'	Coal B.....2' 332'
Very salt sandrock.	Sandrock, very salt.....82' 297'	Conglomerate.....10' 342'
		Coal A.....6' 348'
		Sandstone.....60' 408'

Now, Mr. Blodgett has traced them more or less intermittently down nearly to the county line, where at 115 feet and 151 feet there appear to be coal horizons, as well as lower down at 177 feet to 184 feet, just above a well-marked sandstone. We pick them up in Saginaw county in the well of Wm. Mayberry, on the S. W. ¼ of the N. E. ¼ of Sec. 3:

White clay	20	20
Blue clay	80	100
Soft rock	14	114
Hard rock	1	115
Coal (fresh water)	2' 6"	117' 6"
Rock	23	140' 6"
Coal	3	143' 6"
Hard rock with a brackish water.....	10	153' 6"

It is reported that there is coal in another well on the place at 200 feet depth, and extensive persistent and water-bearing sandstone for over 200 feet.

An imperfect record or two help to bridge the gap of two miles to the basin of coal which has been proved up around Arthur. From the records, for which we have to thank J. W. Messner, we select three:

NO. 3.		
Red clay	18	18
Blue clay	54	72
Hardpan	6	78
Blue rock	5	83
Slate	1	84
Coal (Verne)	3' 3"	87' 3"
Fire-clay	1' 1"	88' 4"

This coal occurs as thick as 42 inches, is usually from 90 feet to

100 feet down, and sometimes there are two, as in the following hole.

NO. 4.		
Red clay	18	18
Blue clay	56	74
Hardpan	8	82
Blue rock	9	91
Slate	0' 6"	91' 6"
Coal (Upper Verne) F.....	0' 10"	92' 4"
Fire-clay	3'	95' 4"
Blue rock	3'	98' 4"
Slate	1'	99' 4"
Coal (Lower Verne) E.....	2' 6"	101' 10"
Fire-clay	3' 8"	105' 6"
Blue rock	19	124' 6"
Sandrock	11	135' 6"
Blue rock	6	141' 6"
Slate rock	0' 6"	142
Coal (Middle rider?) D.....	1' 4"	143' 4"
Blue rock	8' 4"	151' 8"
White rock	9' 6"	161' 2"
Blue rock	7' 6"	168' 8"
Slate rock	1	169' 8"
Coal (Saginaw seam) C.....	1' 6"	171' 2"
NO. 5.		
Red clay	15	15
Blue clay	56	71
Hardpan	9	80
Blue rock	6	86
Sandrock	3	89
Slate	3	92
Coal (Verne) F.....	1' 8"	93' 8"
Fire-clay	2	95' 8"
Sandrock	24	119' 8"
Blue rock	20	139' 8"
Slate	3	142' 8"
Blue rock	7	149' 8"
Sandrock	18	167' 8"
Blue rock	8	175' 8"
Slate	3	178' 8"
Coal (Saginaw?) C.....	1' 8"	180' 5"
Fire-clay	4' 6"	184' 11"
Sandrock	12	196' 11"
Blue rock	2	198' 11"
Slate	2	200' 11"
Fire-clay	2	202' 11"

The following is a test well (No. 6) on the Oliver farm, Sec. 15, at Arthur, by J. Russell:

Red clay	16'	
Blue clay, firm	35'	51'
Blue clay, very soft.....	23'	74'
Hardpan	30'	104'
Loose sandrock	15'	119'
Black slate	2' 6"	121' 6"
Coal	2' 2"	123' 8"
Sandy fire-clay	7' 9"	125' 5"

125 ft. 5 in.

It is plain that the Blumfield correlations are rather artificial, especially that of the Middle Rider. It is possible that the thickest seam rolls between 100 feet and 140 feet depth and is continuous. From some points of view it is more likely that D of the record just cited is the Lower Verne and the coals above the Upper Verne and Upper Rider respectively.

The development of the mine of the Barnard Coal Co. will prob-

ably settle the question. This mine is on the N. E. $\frac{1}{4}$ of the N. W. $\frac{1}{4}$ of Sec. 18, T. 12 N., R. 6 E., and the coal is about 140 feet deep. No tests of this coal, known as the Uncle Henry,* are yet known to me, however.

The following record of a hole put down by J. Russell for J. B. Peter on an adjacent forty-acre lot, the S. W. $\frac{1}{4}$ of the N. W. $\frac{1}{4}$, Sec. 18, T. 12 N., R. 6 E., shows the section down to the coal:

September 22, 1894.

Red clay	12'	13'
Blue clay	60'	72'
Hardpan and boulders	4'	78'
Hard sandrock	3' 6"	79' 6"
Sandy fire-clay	6'	85' 6"
Black shale	8' 3"	83' 9"
Coal	1' 6"	90' 3"
Soft light slate	1'	91' 3"
Soft dark slate	10' 11"	102' 2"
Harder dark slate	4'	106' 2"
Coal	1' 5"	107' 7"
Light slate	5'	113'
Hard black slate	10' 7"	123' 7"
Coal, good	2'	125' 9"
Coal, poor	1' 11"	127' 8"
Bottom slate	2' 6"	130' 2"

If the three coals here shown are correlated with D, E, and F of Arthur and Munger, then the Barnard or "Uncle Henry" coal is the Middle Rider. In some ways it would be more natural to consider it the more persistent Lower Verne. But the quality is said to be better than in that seam.

Working west toward Saginaw, there are indications and records of coal horizons at no great depth all along, but the first boring of considerable depth and accurate record that we have is that of W. T. Chappell, on the farm of D. A. McDonald, on the S. W. $\frac{1}{4}$ of the N. W. $\frac{1}{4}$ of Sec. 16, T. 12 N., R. 5 E., as follows:

Clay	81'	81'
Hardpan	6'	87'
Sand and gravel	4'	91'
Sandrock	21' 6"	112' 6"
Gray shale	4'	116' 6"
Sandrock	61' 6"	178'
Slate	6"	178' 6"
Coal (Saginaw seam)	4' 6"	187' 10"
Fire-clay	0' 8"	179' 6"
Sandrock	2'	181' 6"
Dark clay shale	46'	227' 6"
Light clay shale	6"	228'
Gray shale	44' 6"	273' 6"
Sandrock	18'	291' 6"
Coal and rock (lowest coal)	8'	299' 6"
Fire-clay	1'	300' 6"
Sandrock	1' 6"	302'

According to Mr. Henriett, the driller, a well which he put down 539 feet on the N. E. $\frac{1}{4}$ of Sec. 14, near by (T. 12 N., R. 5 E.), struck

*There is a Barnard Coal Co., *limited*, in West Saginaw.

somewhere between 313 feet and 340 feet a rock with a 32° salt brine, which must almost certainly be the bottom of the series (292'-398' of the first well). Consequently, we may infer that the McDonald well is pretty nearly through the coal series, and the lowest coal struck is the lowest of the series.

Not very far away there is a well nearly equally deep. The record (the Gage farm on Sec. 9, T. 12 N., R. 5 E.) is interesting, for it shows no heavy top sandstone nor coal, as follows:

	Feet.	Feet.
Clay	86	86
Hardpan	2	88
Sand and gravel	2	90
Soft shale	12	102
Gray shale	69	171
Sandstone	2	173
Gray shale	10	183
Black shale	2	185
Gray shale	8	193
Black shale	15	208
Brown shale	13	221
Gray shale	17	238
Sandstone	18	256
Gray shale	2	258
Blue shale	10	268
Gray shale	12	280
Hard rock	1	281
Soft shale	11	292

At McDonald's we find mainly sandstone down to 178 feet. This sandstone probably appears also on Sec. 21, two miles south in Heavenrich's borings (from about 90 feet to 150 feet), where it is nearly clean enough for a glass sand. I think we are safe in assuming it continues to the Schaitberger and Eastman farms on Sec. 29, Wiggins' place on Sec. 33, and the Kochner farm on Sec. 3, T. 14 N., R. 5 E., though there it is split up with thin seams of coal.

It appears also to be the first rock met in the old salt well and in almost all the wells in the northeast part of Saginaw, e. g., that of the Bearer Block, and the numerous city wells, which find abundant water in the first 150 feet or less, so that I think we can trace it without break in continuity to the upper part of Eddy's well, near the river, 700 feet south of Genesee Ave. bridge, through a city well at the corner of Michigan Ave. and Davenport, which is in a heavy sandstone, and another at the corner of Michigan Ave. and Clark St. (coarse sandstone from bedrock at 91 feet to the bottom at 141 feet).

The lower vein of coal was found in all three holes, but variously split up. When we consider that the salt wells near by are less than 750 feet deep, we may be reasonably sure that this well is

nearly through the coal-bearing series, and that the coal at 282 feet is not that of the Chappell-Fordney mine.

The Eddy well record is as follows:

NO. 1.			
Surface sand	28'	28'	
Clay	54'	82'	
Hardpan	48'	130'	
White sandrock	41'	171'	
Dark sandrock	12'	183'	
Black shale (Saginaw seam).....	8'	191'	
Sandrock	1'	192'	
Hard slate	4'	196'	
Limerock	2'	198'	6"
Slate and sandrock	4'	203'	6"
Coal (Lower rider)	0'	203'	5"
Fire-clay	7'	210'	5"
Dark blue shale.....	64'	274'	10"
Dark slate	4'	279'	4"
Coal (Lower coal)	3'	282'	7"
Shale and sand	6'	288'	7"

Thus the correlation suggested with the first salt well seems proper.

Eddy's well brings us within two miles of the important coal basin of West Saginaw, in which the Pere Marquette No. 2, Chappell-Fordney and Riverside mines are located. If we go any further southwest, however, the upper sandstone is absolutely gone from the records with no trace. It apparently does not thin out to a feather edge, as if it rose above the coal basin. Especially on the east side are holes which show the sharp line. Neither does it dip down beneath the coal basin, at least there is no thick sandstone in the first two hundred feet or more. The fact that the salt wells deepen to the south makes it unlikely that the sandstone has, either by a fault or fold, passed above the line of the bedrock surface. The only alternative seems to be that it drops suddenly out, being a bar behind which the upper coals of the East Saginaw coal basin were formed, as shown in Plate IX.

As soon as we leave this capping sandstone the bedrock surface seems to dip to the west and the amount of drift becomes greater.

The Barnard,* Chappell-Fordney, Pere Marquette No. 2, Riverside, and Imperial mines are in the Saginaw seam. The three first are in the city limits of West Saginaw, the Riverside is opposite on the south bank of the Tittabawassee, while the Imperial is on Sec. 7 of James Tp.

*This is the Barnard Coal Co., limited, which has a shaft on the west side of Saginaw river. The tippie of the Pere Marquette shaft was transported there bodily. Besides there is the Barnard Coal Co. operating about 6 miles east. Their coal is known as "Uncle Henry" coal.

A typical section in West Saginaw is the following:

	Feet.	Feet.
Clay	94	94
Hardpan	8	103

(The surface deposits are often over 150 and sometimes over 180 feet thick. The maximum depth within two miles of Saginaw is probably not less than 260 feet. In such cases of course the upper beds are cleaned out.)

Slate	18'	120'
Coal (Verne)	0' 3"	120' 3"
Fire-clay	2'	122' 3"
Gray shale	7'	129' 3"
Slate	4'	133' 3"
Fire-clay	8'	139' 3"
Slate	5'	144' 3"
Fire-clay	10'	154' 3"
Sandy shale	4'	158' 3"
Fire-clay	2'	160' 3"
Slate	8' 5"	168' 8"
Coal (Saginaw seam)	2' 7"	171' 3"

(This is the one mined. It is more usually near 200' deep where thick enough to work.)

Fire-clay	24'	195' 3"
Sandy shale	6'	201' 3"
Slate	11'	212' 3"
Sandy shale	2'	214' 3"
Slate	7'	221' 3"
Sandy shale	8'	224' 3"
Slate	14'	243' 3"
Fire-clay	1'	224' 3"

There are usually one or two coals, in the first 140 feet, of the type of the Verne coals, and when the Saginaw seam is extra deep—190 to 200 feet, there is apt to be some coal at about 160 feet. Two coals are said to be traceable in a general way, though with varying thickness, across James township and past Garfield to St. Charles, and there are enough holes to be pretty sure of their connection, with occasional barren areas, all over Sections 21, 22, 27, 28, 33, and 34. A Section E—W to Paines Station is shown in Plate IX.

The Saginaw seam appears to be the lowest coal seam shown in the boring of the Saginaw Board of Trade (S. G. Higgins' report) the record of which runs as follows, and was put down near the Palmerton Woodenware factory near the south end of the city, near the corner of Holmes and Brant streets (1,000 paces N., 200 W., Sec. 34, T. 12 N., R. 4 E.):

Test hole No. 10.

Lake Clays—		
Clay	70'	70'
Hardpan	2'	72'
Glacial Deposits—		
Sand and gravel.....	7'	79'
Hardpan	12'	91'
Sand and gravel.....	3'	94'
Hardpan	9'	103'
Sand and gravel.....	3'	106'

Test hole No. 10.—*Continued.*

Coal Measures—

Blue shale	4'	110'
Gray shale	1' 6"	111' 6"
Black slate	6"	112'
Coal (Verne)	1'	113'
Gray shale	3'	116'
Sand and gravel	1'	117'
Gray shale	23'	140'
Coal (Middle rider)	6"	140' 6"
Fire-clay	5'	145' 6"
Light gray shale	4'	149' 6"
Sandrock	5'	154' 6"
Light gray shale	28' 6"	181'
Coal (Saginaw seam)	4"	181' 4"
Fire-clay	4'	185' 4"
Sandrock	2'	187' 4"
Gray shale	20'	207' 4"
Sandrock	13'	220' 4"
Dark gray shale	5'	225' 4"
Light gray shale	33' 4"	258' 8"

This is but little over half a mile from the Chappell-Fordney mine. It is very curious that the samples of the South Saginaw well should show so little coal when they are between the well just recorded and the Saginaw coal mine shaft (See Plate V), the record of the exploratory boring of which ran as follows:

Clay	54'	54'
Sand and gravel, which turned out in the shaft to be a diagonal streak of a few inches	3'	57'
Clay	37'	94'
Sand	4'	98'
Hardpan to bedrock	5'	103'
Slate	1'	104'
Coal	1"	104' 1"
Gray shale	18'	122' 1"
Slate	6' 6"	128' 7"
Coal	4"	129' 11"
Hard sandy clay	1'	129' 11"
Gray shale	5'	134' 11"
Strong black slate	12' 2"	147' 1"
Coal, this is the coal mined	3' 3"	150' 4"
Fire-clay	18'	168' 4"
Sandrock	34'	202' 4"
This sandstone may replace the lower coal.		
Sandy shale	3'	205' 4"
Slate	16'	221' 4"

This is a little south and about 1,700 feet east of the north quarter post of Sec. 31, T. 12 N., R. 5 E.

Though considerably higher I take the coal mined on the east side to be the same seam as that on the west side. The coal seams on the east side appear much nearer together and the main seam rises rapidly to the Pere Marquette No. 1 shaft near the center of Section 32, where it is but 135 feet down. Within one-half mile to the east it rises 22 feet more and comes too near the surface to

be profitably workable, being in points on J. Stimson's farm covered by only four feet of soft roof.

Here we have the curious phenomenon of coal seams running up and abutting against a sandstone while a mile or two north their supposed equivalents appear to lie under it. This sandstone we may imagine to have been a northward travelling sand dune or bank—for this implies that the conditions of sandstone formation were gradually transferred from the former place to the latter, if we suppose the coal strictly contemporaneous. On the S. W. of Section 21, a mile and more south, are a number of holes drilled by M. and C. Heavenrich. Beneath the usual amount of drift, 95 to 102 feet, comes first a white sandrock, almost suited for glass sand, apparently the same as that first met in the McDonald wells on Section 14. This continues to 150 feet or more. Then in the next 30 feet are two or three quite persistent coal seams. Less than a mile away at Mrs. G. Schaitberger's place in the W. $\frac{1}{4}$ of the S. W. $\frac{1}{4}$ of Section 29 we find the drift slightly deeper (115 feet), and the sandstone still present down to 145 feet. The Eastman farm, on the S. E. $\frac{1}{4}$ of Sec. 29 also shows the same sandstone from 103 to 156 feet, but with a foot of shale at 148 feet.

But the well of the O'Donnel Spencer Co., near the crossing of Genesee Ave. and the Pere Marquette R. R. (S. E. $\frac{1}{4}$ of Sec. 30) less than a mile away is entirely different, to-wit (A. M. McMillan, driller):

	Feet.	Feet.
Clay	72	72
Hardpan	43	115
Black shale	4	119
Coal	1	120
Soapstone	2 $\frac{1}{4}$	122 $\frac{1}{4}$
Coal	2 $\frac{1}{4}$	125
Soapstone	45	170
Hard sandstone	8	173
Water bearing sandstone.....	6 $\frac{1}{2}$	179 $\frac{1}{2}$

This is the well that started the coal fields of Saginaw.

Again the well on J. Stimson's place in the N. E. $\frac{1}{4}$ of Sec. 32, not much west of the Pere Marquette R. R., begins in shale and soon strikes the coal mined in the Pere Marquette No. 1 shaft.

When the Eocarboniferous ceased to be a land surface, at the old salt well, sandstone was first formed there, apparently. The conditions of sandstone building seem to have moved to Carrollton and then back to the first salt well, where they were at the time of the Saginaw seam.

Returning to the Palmerton Woodenware factory on Sec. 34, we follow the Saginaw seam down on the Fitzhugh farm (Sec. 3 and Sec. 4, T. 11 N., R. 4 E.), where the Riverside mine is located, and the seam reaches 41 and 42 inches at about 182 feet, and there is also a seam at 158 to 163 feet. We cross, however, a deep gravel filled channel (or "washout") which at the Merrill bridge is over 150 feet to rock. It is a branch of the main channel, which is 250 feet or more deep between Shattuckville and Paines. One minor channel runs east towards the Standard mine, another runs south on Section 10. Another channel runs N. E. from Section 7, where the Imperial Coal Co. have a shaft about 180 feet deep in a basin of coal. Thence it is about two miles to the following well on Sec. 24, T. 11 N., R. 3 W.:

Surface	44'	44'
Hardpan	20'	64'
Gray slate	7'	71'
Sandroek	8'	79'
Gray shale	5'	84'
Gray slate	13'	97'
Coal (Upper Verne).....	1' 8"	98' 8"
Fire-clay	2'	100' 8"
Gray slate	4' 4"	105'
Sandroek	17'	122'
Coal (Lower Verne)	6"	122' 6"
Fire-clay	6'	128' 6"
Black slate	6'	135'
Fire-clay	3'	138'
Sandroek	1' 6"	139' 6"
Fire-clay	3' 6"	143'
Gray shale	1'	144'
Blue slate	6"	144' 6"
Gray slate	10'	154' 6"
Sandroek	12'	166' 6"
Gray slate	3' 6"	170'
Black slate (Middle rider?).....	6"	170' 6"
Gray slate	10' 6"	181'
Black slate	4'	185'
Coal (Saginaw seam)	1' 2"	186' 2"
Fire-clay	2'	188' 2"
Sandroek	3'	197' 2"

These three coal horizons can be followed in a series of borings on Prairie Farm to the south through Sec. 25, and 26, though frequently one or the other drops out. There is, as at St. Charles, at times "cannel coal" on top of the Saginaw seam. Coal also appears at 160 to 180 feet depth, a little above the Saginaw seam—the Middle Rider. The nearest record to the Verne mine on Sec. 23, which shows the coals in fair shape is the following on Sec. 16. (See Plate IX, section C.)

Clay	27'	27'
Hardpan	3'	30'
Sand	2'	32'
Hard clay	14'	46'
Gray slate	20'	66'
Slate	10'	76'
Sandy shale	10'	86'
Sandrock	37' 6"	123' 6"
Coal (Lower Verne)	7' 6"	124'
Fire-clay	7'	131'
Gray shale	9'	140'
Sandrock	21'	161'
Slate	9'	170'
Coal	2"	170' 2"
Sandrock	15'	185' 2"
Gray shale	4'	189' 2"
Slate	15' 6"	204' 8"
Coal (Saginaw seam perhaps)	8"	205' 4"
Fire-clay	5'	210' 4"
Gray shale	6'	216' 4"
Slate	6'	222' 4"
Poor coal	1'	223' 4"
Slate	3'	223' 4"
Fire-clay	2'	228' 4"
Sandrock	2'	230' 4"

This brings us but two miles from the Verne mine, the section of which has been given.

About the same distance away we strike the explorations around Foster's. On Section 12 of Albee, there are the Verne coals probably at 86' 9" (1' 3") and 103' 9" (6") and another, probably the Middle Rider, at 156' 6" (1 foot).

On the farm of Mr. Herpel (Sec. 7, T. 10 N., R. 4 E.), Mr. Higgins gives the following records:

Surface	64' 6"	64' 6"
Sandrock	28' 6"	93'
Black slate (Lower Verne)	6"	93' 6"
A mile north there was 2 in. at 67' 8" and 3" at 83' 5"		
Gray shale	26' 6"	120'
Sandrock	23'	143'
Gray shale	1'	144'
Coal	6"	144' 6"
(At 145' a mile north there was two inches of coal).		
Fire-clay	1'	145' 6"
Light gray shale	8'	153' 6"
Dark gray shale	5' 6"	159'
Sandrock	15'	174'
Gray shale	11'	185'
Coal (Saginaw seam)	2"	185' 2"
White shale	6'	191' 2"
Black slate	7'	198' 2"
Hard white rock	4'	202' 2"
Sandrock	5'	207' 2"

Returning to the Prairie farm records and working southwest on Sec. 12, we have the following record:

Clay	47'	47'
Sand and gravel	9'	56'
Gray shale	52'	108'
Sandrock	35'	143'
Gray shale	6'	149'
Sandrock	51'	200'
Fire-clay	3'	203'
Slate	10'	213'
Coal	3"	213' 3"
Fire-clay	4'	217' 3"
Slate	16'	233' 3"
Coal	4"	233' 7"
Fire-clay	2'	235' 7"
Gray sandrock	1'	236' 7"

This is a hole of interest, not showing the Verne coals, but showing a heavy sandstone which is quite widespread around St. Charles, and is close above the Saginaw seam in the mine of the St. Charles Coal Co.

This sandstone is not persistent, for on the N. half of the S. W. $\frac{1}{4}$ of Sec. 15 we have borings of the Robert Gage Coal Co. The following is extra deep:

Clay	25'	25'
Hardpan	18'	41'
Slate	58'	99'
Coal (Upper Verne?).....	8"	99' 3"
Other holes in the same 80 acres show a few inches of coal at 97' 3" and 106' 10" and 114' 6".		
Fire-clay	12'	111' 8"
Sandy shale	49'	151' 8"
Light shale	15' 7"	167' 3"
Coal (Saginaw seam?).....	2' 9"	170'
Other holes show 9" of coal at 153' 3" and 2' 5" at 157' 7".		
Other holes show 3' 10" at 168' 10" and 3' 3" at 168' 5", etc., north at the Robert Gage shaft it is down to 180' again.		
Fire-clay	15'	185'
Slate	20'	205'
Fire-clay	7'	212'
Sandrock	15'	227'

On the southwest $\frac{1}{4}$ of the northwest $\frac{1}{4}$ of Sec. 16, the sandstone we were speaking of reappears, however, as shown in this boring:

	Fest.	Fest.
Clay	22	22
Hardpan and gravel.....	18	40
Sand	4	44
Hardpan	8	52
Light slate	63	115
Sandrock, with streaks of slate	72	187
Dark slate	4	191
Sandrock	7	198
Slate	3	201
Coal (Saginaw seam)	4	205
Sandy fire-clay	9	214

This is close to J. H. Somers No. 2 shaft and a little over half a mile from that of the St. Charles Coal Co.

In this mine the sandstone was generally parted from the coal by a few inches of black slate, but to the north of the shaft the coal rises 22' in 150' and runs right into the sandstone. There are little streaks of coal and pebbles of Fe CO_3 in the sandstone which varies from 30' to 100' thick. Such rolls account for the depth of the seam varying from 166' to 200' and a little more.

Similar pebbles of Fe CO_3 are found in a sandstone at Williamston and elsewhere.

None of the above records show the Lower Verne well developed, but in the Robert Gage shaft near the west $\frac{1}{4}$ post of Section 15, T. 10 N., R. 3 E., there were three small coal seams above

the main Saginaw seam, and in the shaft of the Michigan mine near the north $\frac{1}{4}$ post of Sec. 8 (Black Pearl, Plate VII), where the main seam is about 190 feet down, there were 20" to 30" of coal at 128', which were mined at first but spoiled the quality of the coal, for it contained much more sulphur than the lower coal. The same seam occurs in the J. H. Somers No. 1 shaft on Sec. 3. It is said to be more pockety and irregular. The following test holes by the Higgins committee show this in the record. No. 11 is about 10 rods west and No. 13 is about 30 rods north of No. 12.

No. 11.		No. 12.		No. 13.
Sand.....	8' 8'	10'	10'	
Clay.....	13' 21'	20'	30'	
Gravel.....	1' 22'	1' sand.....	31'	
Clay.....	25' 47'	17'	48'	
Gravel and sand.....	1' 48'	1' sand.....	49'	50' 50'
Blue shale.....	37' 85'	46' clay and shale.....	96'	4' 54'
Hardpan and gravel.....	2' 87'	10' gray rock.....	105'	6' black shale..... 60'
Light gray shale.....	13' 100'			
Sandrock.....	12' 112'	25'	130'	8' white shale..... 68'
Coal.....	2"			
Upper Verne?				
Gray shale.....	2' 114' 2"	6'	136'	35' 103'
		2" slate.....	138' 2"	
Coal.....	2" 114' 6"	2' 3"	138' 5"	2" 103' 2"
Lower Verne?				
Fire-clay & sandrock.....	22' 146' 4"	5'	143' 5"	6' 109' 2"
Gray shale.....	2' 6" 148' 10"	11'	154' 5"	30' 139' 2"
Black slate.....	3' 151' 10"	1'	155' 5"	4' 143' 2"
Place of Middle Rider?				
Gray shale.....	4' 155' 10"	26'	181' 5"	8" coal..... 143' 10"
Dark gray shale.....	3' 158' 10"			26' 179' 10"
Light gray shale.....	14' 172' 10"			
Brown slate.....	7' 179' 10"	6'	187' 5"	2" 180'
Black slate.....	6" 180' 4"			
Coal (Saginaw seam).....	2' 182' 4"	2'	189' 5"	6" 180' 6"
Salt.....	1' 183' 4"			
Fire-clay.....	1' 184' 4"	6"	189' 11"	2' 6" 183'

It is said that southwest of No. 12 the upper coal is 18 inches thick; that 40 rods east it is about 2 feet thick, and that 30 rods east of south there is 2' 6" at 123' 2".

Before leaving St. Charles it is well to call attention again to the fact that the seam now worked is not the lowest of the coal measures. Unfortunately I have no accurate record of the beds below exposed in the salt wells recently put down, but I am authoritatively informed that from 500' down there was a good deal of the limerock of the Eocarboniferous (as at Garfield), and at about 425' the last coal seam was struck, a few inches thick, while the Napoleon is from 700' to 810'.

Thus the lower seams are present as they are around Bay City, though as yet we know very little about their thickness.

The Saginaw seam can be followed north from St. Charles and west from the Prairie farm explorations already mentioned, varying in thickness but at about the same level or deeper. The upper coals also persist, as is shown by the following record of a hole close to the old salt well at Garfield, A. W. Johnson, driller.

Surface sand	2'	2'
Blue clay	15'	17'
Hardpan	42'	53'
Sandrock	8'	67'
Sandy shale	63'	130'
Coal (Upper Verne)	1' 6"	131' 6"
Fire-clay	2'	133' 6"
Slate	5'	138' 6"
Coal (Lower Verne)	4"	138' 10"
Sandy fire-clay	12'	150' 10"
Sandrock	2'	152' 10"
Water bubbled up and the casing was magnetic so that calipers clung to it.		
Slate	45'	197' 10"
Sandrock	14'	211' 10"

This possibly may not have gone quite far enough to strike the Saginaw coal, which appears in a hole a mile east on the S. W. $\frac{1}{4}$ of Sec. 15, T. 11 N., R. 3 E., whose record runs:

Blue clay	40'	40'
Hardpan	20'	60'
Very hard rock	8"	60' 8"
Soft sandrock	1' 6"	62' 2"
Gravel	2'	64' 2"
Bedrock here—		
Sandy shale	70'	134' 2"
Verne coals absent—		
Light slate	30'	164' 2"
Dark slate	30'	194' 2"
Coal	2' 8"	196' 10"

These two holes are quite comparable with the hole on Sec. 24, T. 11 N., R. 3 E., whose record we have cited just above.

If we go much farther north the bedrock surface begins to drop off into the deep channel which runs west from Saginaw. For instance at Paines we have the following record:

	Feet.	Feet.
Surface to bedrock.....	208	208
Coal, perhaps the Saginaw seam.....	2	210
Soft sandstone	32	242
Soft sandstone	20	262
Dark shale	28	290
Sandstone	32	322
Black shale	30	352
(Probably the horizon of the lower coal.)		
Fire-clay	2' 6"	354' 6"

Four miles north it usually runs from 225' to 240' to bedrock. In the west part of the county the bedrock surface is deep.

For this reason the northwest part of the county has been comparatively little explored. The following, however, is the well put down by J. H. Whitney on the N. $\frac{1}{4}$ of the S. W. $\frac{1}{4}$ of Sec. 24, T. 12 N., R. 1 E. No. 1 was put down on the S. W. $\frac{1}{4}$ of the S. W. $\frac{1}{4}$ of Sec. 26.

Clay	8'	8'
Sand	6"	8'
Clay	28'	35'
Sand	20'	55'
Clay	18'	71'
Sand	5'	76'
Soft clay	54'	130'
Sand	7'	137'
Soft clay	25'	162'
Clay	2'	164'
Dry sand and gravel	18'	180'
Clay	15'	195'
Sand	2'	197'
Sandrock	8'	205'
Gray soft shale	1'	206'
Sandrock	2'	208'
Sandy shale	2'	211'
Sandrock	3'	215'
Gray shale	5'	220'
Sandrock	4'	224'
Coal (possibly the Saginaw seam)	1'	225'
Sandrock	4'	230'
Sandy white shale	9'	239'
Sandrock	20'	260'
Sandy shale	30'	290'
Sandrock	30'	320'
White sandy shale	20'	340'
White sandrock	7'	347'
Dark gray shale	6'	353'
Dark sandrock	5'	358'
Dark shale	5'	363'
Sandrock	1'	364'
Gray shale	3'	367'
White sandrock	2'	369'

Thus in passing west though we know that the Eocarboniferous strata are dipping that way, we can find no more trace of a general dip of the coal-bearing series than we did in Bay county. The general level of the country is rising.

In the southeast part of the county the distance to bedrock is not usually great, some 60 to 100 feet, and sandstone with plenty of water is soon obtained. Some coal is found, but apparently not enough to attract investment.

Tuscola County.—A detailed report upon this county is in preparation by C. A. Davis, to which reference must be made for more detailed information. There is quite a little coal around Unionville at 118 to 130 feet.

On the other side of the valley, which cuts out the coal southeast of Sebewaing, we find the coal reappearing and extending through Columbia and even into Elmwood. This is shown, for instance, by the well of T. McCarty on the southeast quarter of Sec. 24, T. 14 N., R. 9 E., in which under about 84 feet of blue clay and 14 feet of sandstone, 3 feet of coal was said to have been met. I saw some of the coal. There was water in the sandstone.

The coal beds seem to be mainly confined to the part of the county northwest of the Cass, though there may be isolated patches to the south in T. 10 N., R. 7 and 8 E., especially since two foot seams of coal are reported from Vassar at 82 feet and 126 feet.

The recent well at Caro, 15 feet above Cass River, struck under 113 feet of surface deposits, a limestone which appears to be Eocarboniferous, and very much like the Bayport limestone, though there are two feet of black shale at 240 feet, the record being (A. J. Scott, driller):

Drift	113 ft	113 ft
Limestone, compact, pyritiferous	7	120
Green shale	25	145
White sandstone, with water	40	185
Dolomitic limestone	5	190
White sandstone	50	240
Black shale	2	242
Calcareous sandstone	10	252
Black shale	1	253
Sandstone, greenish white, kaolitic, with coaly specks and calcareous layers	29	282

The flow is strong and the water very slightly brackish.

The thickness increases probably quite fast to the northwest. The following record, by J. Russell on Sec. 4, T. 13 N., R. 9 E., is a rather full one and the base of the coal-bearing series appears to be at 170' 3":

Red clay	11'	11'
Blue clay	49'	60'
Hardpan	15'	75'
Soap rock	14' 6"	89' 6"
Hard streak	6"	90'
Water here.		
Slate rock	27'	117'
More water.		
Black slate rock	11'	128'
Light slate rock	2'	130'
Dark sandrock	5' 6"	135' 6"
Hard black slate	6"	136'
Sandrock	4'	140'
Black and white rock mixed	1'	141'
Fire-clay or white rock	3'	144'
Black and white rock mixed	1'	145'
Sandrock	9"	145' 9"
Coal	1' 8"	147' 5"
Dark slate rock	1'	148' 5"
Light slate rock	1'	149' 5"
Fire-clay or white rock	1' 2"	150' 7"
Light slate rock	1' 1"	152' 8"
Dark slate rock	6' 7"	159' 5"
Light slate rock	11'	170' 3"
Eocarboniferous.		
Lime rock	20'	190' 3"
Sandrock	18'	208' 3"

The base varies a good deal with the depth. When the Eocarboniferous limestones do not come until a considerable depth, heavy sandstone sometimes occurs, with some coal above or below it.

This is illustrated in the following records:

	Sec. 18, T. 14 N., R. 9 E.		Sec. 18, T. 14 N., R. 9 E.	
Clay	67'	67'	68'	68'
Hardpan	10'	77'	7'	75'
Sandrock	25'	102'	99' 4"	174' 4"
Slate	13'	115'		
Coal				
Sandrock	55'	170'		
Coal			3' 1"	177' 5"
Hard gray sandrock	18'	188'		
Slate rock	5'	193'	6'	183' 5"
Light slate	6' 7"	199' 7"	Sandrock 4'	187' 5"
			Lime	191' 5"

Compare also the following record No. 8 of Mr. Higgins' series of tests:

Surface	47'	47'
Blue shale	7'	54'
Light gray shale	2'	56'
Dark gray shale (Verne coal horizon?).....	21'	77'
Sandrock	112'	199'
Gray shale with layers of coal (Saginaw seam) 3'	3'	202'
Soft fire-clay	6"	
Hard fire-clay	3'	206'
Red sandstone with layers fire-clay.....	18'	224'

A large amount of records in Tuscola county have been preserved, more than can be printed here.

This is a fair illustration of the tests around Tuscola, which Mr. Zagelmeyer says run up to 80 feet of drift, then 160 feet of white sandrock, then 6 to 22 inches of coal under the sandrock. This sandrock probably outcrops in the river, and coal also occurs above it, which is probably one of the Verne coals.

It is not far, however, to F. With's well, near the S. W. corner of Sec. 30, T. 12 N., R. 7 E., where this thick sandstone has begun to break up, though water comes in freely at 150 to 200 feet. The record is:

Clay	56'	56'
Hardpan	28'	84'
Sandy shale	32' 4"	116' 4"
Blue shale	12' 4"	128' 8"
Black shale	1' 4"	130'
Gray shale	24'	154'
Black shale	1'	155'
Hard sandy shale, water along here.....	11'	166'
Gray shale	6'	172'
Very hard sandy shale.....	18'	190'
Sand not so hard	12' 8"	202' 8"
Gray shale	1' 4"	204'
Hard sandrock	8'	212'
Black shale (Horizon of Saginaw seam?).....	10"	212' 10"
Sandrock	2' 2"	215'
Black shale	2' 4"	217' 4"
Fire-clay	2' 8"	220'
Hard sandrock	6'	226'
Black slate	1'	227'
Fire-clay	2'	229'
Blue shale	3'	232'
Coal (Lower Rider or Saginaw).....	8"	232' 8"
Fire-clay	2' 1"	234' 9"
Blue shale	3' 3"	238'
Hardrock	1'	239'
Blue shale	9'	248'
Black slate (Lower Rider).....	2'	250'
Fire-clay	4'	254'
Blue shale (Lower coal).....	21'	275'
Black slate	3'	278'
Fire-clay	1'	279'
Sandrock	1'	280'

The heavy sandstone we have referred to, it is easy to mistake for the basal sandstone or Parma sandstone, which indeed it may merge into near the margin of the basin, and I have referred it to the Parma sometimes. But more numerous records show that the

sandstone zigzags through the formation as we have seen around Saginaw.

Coal has been found down to Elva and there may be some other pockets beyond. Near Millington on the old Blanchard farm 3 feet 7 inches of coal is reported at 190 feet. Around Unionville, near which there appears to be a dislocation and to the northwest of the Cass River, most wells show at least small seams of coal at various depths, but the records, while very numerous, are hardly near enough yet to connect the different coals with any precision, especially if there are faults.

Records in the southeast part of the county in Kingston show clearly that no coal is to be expected there.

Sanilac County.—This county has been reported by Dr. C. H. Gordon, Vol. VII, Part III.

The rocks appear to be entirely Eocarboniferous, and while fossil plants akin to those of the coal measures may be found, and indeed coaly streaks, there is little possibility of anything approaching a workable deposit of coal, and explorations for it are not worth while.

Kent County.—No coal has ever been struck in place in this county, so far as I know, but considering that we have at Grand Rapids beds almost identical with those at Bay Port, it would be natural to expect coal corresponding to the Sebewaing coal in the northeast part of the county heavily buried under drift, unless, as is probable, the bedrock surface dips to the northeast from Grand Rapids, somewhat following the dip of the limestone, for in a well at Saranac there is 227 feet of drift, and the bedrock surface is but 417 feet A. T. The coal series is very likely confined to the east bank of the valley thus made.

Ionia County.—The deep valley indicated by bedrock at 417 A. T. at Saranac probably runs nearly N. and S. into Barry county. Then the bedrock surface rises upon an escarpment of coal measure sandstones until it outcrops near Ionia and Grand Ledge.

On Sec. 26, Ionia township, T. 7 N., R. 6 E., Mr. Jas. Horrocks has put down two deep wells. Of the one put down in April, 1900, he gives the following record:

Surface and sandstone (Woodville?).....	75'	75'
Blue slate	20'	95'
Black slate	5'	100'
Coal	2' 2"	102' 2"
Fire-clay	6"	102' 8"
Fine grit stone.....	8'	110' 8"
Blue slate	20'	130' 8"
Small seams, slate, coal, fire-clay, etc.....	43' 8"	174' 4"
Coal	0' 8"	175'
Small seams, slate, coal, fire-clay, etc.....	71'	246'
(Casing 200' 1").		
White sandrock, the Parma.....	87'	343'
Sandstone with a strong flow of water.		
Another well on the same section is 540 feet deep.		

A well for Henry Pierce in South Ionia is said to have gone through (the record is obviously very imperfect):

Iron ore (water)	3' 6"	at	60'
Coal, slaty	1' 2"	at	150'
Hard coal (? black slate or limestone).....	10'		160'
Soft coal	1' 2"		161' 2"
Fire-clay	7'		168'

Combining these with a well for M. W. Yeomans, Rominger's notes, and report of an old well by L. J. Lincoln, by his assistant, from memory, we get the following general idea of the strata:

Surface drift, up to 140 feet.

Sandstone, quarried, variegated red and white, probably Winchell's Woodville, replacing more or less normal coal series, up to 143 feet.

Shales and fire-clay with two or more seams of coal often over a foot thick, from 40 up to 175 feet.

Heavy white sandstones with artesian flows more than 100 feet thick, the Parma, down at 250 to 400 feet depth.

Red sandstone and very salt water at 700 to 800 feet (Marshall?).

Coal is reported a number of times near Ionia at about 200 feet depth.

Wells at Hubbardston 240 and 275 feet deep show that the surface deposits are nearly that thick, the bedrock being sandstone.

Clinton County.—A well in Lebanon township (8 N., R. 4 W.) shows 294 feet of drift here, with coal measure rocks beneath.

The most complete record is that of the St. Johns water-works well given by L. J. Lincoln below, in which down to 608 feet neither coal nor black shale was mentioned. I suspect that part of the sandrock ? of this well may be really limestone or dolomite. Another well put down in 1901 has a quite different record. Some figures from it are given on the extreme right.

St. Johns water-works well, T. 7 N., R. 2 W. Record No. 2:

	Feet.	Feet.	New well.
Blue clay	19	19	
Pipe clay	12	31	
Clay and hardpan	61	92	
Stony and hardpan	19	111	
Granite boulder	2½	113	
Soft clay	10	123	
Gravel and hardpan	13	136	
Hardpan	5	141	153
Base of Drift or Pleistocene—			
Red sandrock	5	146	173
Sandrock	20	166	
Gray sandrock	17	183	
Yellow sandrock	17	200	
To shale rock	14	214	
Shale rock	3	217	
Slate rock	26	243	
Blue sandrock	21	264	
Yellow sandrock	23	287	
Yellow hard and lighter	51	338	
Sandrock	6	344	
Hard blue sandrock	44	388	
Water rock	23	411	
Blue sand, harder	45	456	
Slate	12	468	375
Top of Parma sandstone—			
White sand	10	478	
Water rock sand	17	495	
Blue packed sand	22	517	
White water rock	10	527	535
Blue sand	13	540	
Perhaps beginning of Eocarboniferous lime-			
stone series, Upper Grand Rapids.			
Hard strata	10' 4"	541' 4"	
Blue sand to white	18'	559' 4"	
	3'	562' 4"	
Hard blue sandrock	27'	589' 4"	
Blue shale and sandrock	19'	608' 4"	
(Very hard.)			

The Kniffin well,* however, whose record is given in connection with analysis of the coal, is only three miles or so away, and shows two seams of coal, which appear to have been eroded away at St. Johns. These coals are very likely the Verne coals, and may connect with the coals worked at Grand Ledge and Corunna. In this case it is not at all impossible that the series of sandstones below, may, as at Ionia, split and make room for lower coals.

On the Brown farm near the southeast corner of Sec. 26, T. 5 N., R. 4 W., a coal shaft 52 feet deep, sunk about 1891, was a failure, largely owing to the water encountered, the section being:

Surface (till?)	12'	12'
Very porous sandrock	10'	22'
White sandrock and fire-clay	23'	45'
Slate	7'	52'
Coal	18" to	27"
Fire-clay		54'

Eastward the drift is thicker, on Sec. 24, T. 5 N., R. 1 W., 110 feet to rock.

The Pratt mine of the Grand Ledge district (which see) is just over the line in this county and is the only mine working in the county.

*Pages 105 and 115.

A good coal seam is said to have been found at 330 feet depth at Elsie, and the depth is not unlikely, for it is clear that going northeast the thickness of the coal-bearing series thickens from about 250 feet to 500 or more. The St. Johns well may be entirely in the coal series, and certainly does not get down in the Michigan or Lower Grand Rapids group of gypsum, limestone, shales and salt water.

At Maple Rapids, about 640 feet A. T., much lower than St. Johns, we have the following record:

Hardpan	25	25
Blue clay	3	28
Stones	8	36
Blue clay	28	64
Hardpan	5	69
Sand with water	1	70
Blue clay	6	76
Sand	1	77
Brown clay	7	84
Gravel	2	86
Red sand (water)	82	168
Gray rock	14	182
Red sandstone (hematite)	2	184
Dark shale	31	215
Red shale	3	218
Soapstone	29	244
Light shale	17	261
Coal		261' 2"
Light shale	33' 10"	295
White sandstone (water)	39	334

In a second test a 46 inch seam of coaly shale was struck at 325 feet depth on the farm of Hon. F. W. Redfern.

Shiawassee County.—Owosso and Corunna are one of the best known and steadiest coal districts, fully reported by Rominger in Vol. III. Additional information is given in the reports of C. D. Lawton, when mineral commissioner, and in Vol. V.

Most of the mining has been confined to the east central part of Caledonia township. (See description given with the analyses of the coals of the Owosso and Corunna Coal companies.) The two coals worked in this neighborhood not more than 80 feet down are probably the Verne coals, for there is coal found down to 216 feet, and, as Plate XII of Vol. V shows, there is at least 231 feet of coal measures, excluding the basal sandstone. The coal found at 180 feet depth at the D., G. H. & M. station at Milwaukee, though but six inches thick, may represent the Saginaw seam. W. F. Ward of the Owosso Coal Co. is said to have discovered three and one-half feet of good coal at 195 feet. Continued explorations have developed the coal northeast and north, while to the south of Corunna the wells show almost exclusively sandstones, e. g., at the schoolhouse one-half mile southwest of Corunna:

	Feet.	Feet.
Blue clay	12	12
Sand and gravel	15	27
Rest of surface deposits gray hardpan.....	63	90
Black slate	5	95
Sandstone	227+	322+

The series to the north contains more shale, which comes in, splitting up the sandstone as shown by comparing the record just given with Plate XII of Vol. V, or with the following:

Westhaven Township.

Sandy clay	51	51
Sandrock	4	65
Fire-clay	3	58
Gray rock	3	61
White sandrock	13'	74'
Coal	10"	75
Fire-clay	3	78
Gray rock	6	84
Coal	1'	85'
Fire-clay	2'	87'
Gray slate	2'	90
Fire-clay	7	97
Slate	12'	109'
Coal (Lower Verne?)	3	112'
Fire-clay	3'	116
Gray slate	19	135
Black slate	3'	138'
Gray shale	14	152'
Black slate	10	162'
Gray rock	8	170'
White sandrock	7	177'
Black shale	13	190'
White sandrock	10	209'

Right in the town of Corunna, Sec. 28, we have, according to Mr. W. F. Fowler:

	Court House.	Hotel.
Clay	16'	16'
Sand and gravel.....	4'	20'
Hardpan (till)	62'	82'
Fire-clay	4'	86'
Shale.....	10'	96'
Sandstone	144'+	240'+
With water of Sp. Gr.....	1.001	1.008

The sandstone at the bottom is apparently continuous with that at 55'-135' in Plate XII, Vol. V, and apparently as we pass south the lower coal and shale seams thin out and the sandstones come together.

From Owosso north the depth of the drift is quite variable, as there are numerous channels in the rock surface. Right in Owosso bedrock nearly outcrops and again is 100 feet deep. Kincaid's mine struck a gravel filled channel.

In the township north of New Haven, outcrops occur near Six-mile Creek, but only a few miles away it is very deep to bedrock. The channel probably goes northwest.

Off toward Venice and Hazelton townships (T. 7 and 8 N., R. 4 E.), coal continues in varying thickness, and explorations to a depth of 412 feet, have also been undertaken around the mouth of

Six-mile creek, near the exposures of the upper coal beds which Rominger and Winchell described. This depth carries it into the basal Parma sandstone.*

The following record from Durand, where the general reports are that wells to rock are from 50 to 175 feet deep, say 120 feet deep and more, that McBride has a flowing well 140 feet deep, and that a well 400 feet deep got salt water is interesting, but difficult to interpret.

It seems likely that the bedrock is really at 109 feet instead of 238 feet, as given, and that the "water-bearing gravel, hardpan, and stones" of the record is really a conglomerate. This is indicated by the fact that wells 178 feet deep yield a water with much less lime and more soda than water from shallower wells. Then the black shales beneath are those which have been noted in several other cases near the top of the Grand Rapids group, or more likely the unconformity at the base of the coal measures extends here down to the Marshall—compare the records around Flint.

DURAND WELL RECORD.

	a	b	a	b
Pleistocene.				
Surface clays.....	12'	12'	12'	12'
Quicksand.....	7'	7'	19'	19'
Gravel.....	4'	4'	23'	23'
Hardpan.....	18'	19'	41'	42'
Gravel.....	2'	2'	43'	44'
Hardpan.....	19'	20'	62'	64'
Gravel.....	1'	1'	63'	65'
Hardpan.....	15'	15'	78'	80'
Blue clay.....	10'	10'	88'	90'
Hardpan.....	10'	10'	98'	100'
Gravel.....	2'	2'	100'	102'
Hardpan.....	9'	7'	109'	109'
Brown shale.....	65'	34'	174'	148'
Parma or Napoleon.				
8 in. casing to 176 ft.				
Water bearing gravel.	4'	4'	178'	147'
If this is really under shale it must be a conglomerate.				
Hardpan and stones...	60'	62'	238'	209'
Iron casing 208 feet.				
Grand Rapids or Lower Marshall.				
6 in. casing to 267' 89' farther.				
Black shale.....	108'	107'	341'	316'
Well plugged at 382 feet.				
Blue shale.....	2'	13'	343'	329'
Black shale.....	12'		355'	
Limestone.....	1'	1'	356'	330'
White shale.....	67'	69'	423'	399'
Green shale.....	10'	10'	433'	409'
White shale.....	54'	55'	487'	464'
Blue shale.....	20'	20'	507'	484'
Limestone.....	1'	1'	508'	485'
Blue shale.....	92'	95'	600'	580'
Limestone.....	5'	5'	605'	585'
White shale.....	14'	14'	619'	599'
Blue shale.....	24'	30'	643'	629'
Salt bearing sandstone	5'	5'	648'	634'
Blue shale.....		1'		635'

(a) Record from blue print furnished by R. R.

(b) " " files of Village Clerk. Total depth 636'; cost \$1800; yielded 4 gallons a minute of brine.

*Compare Pl. XLV of Vol. V.

At Bennington, the well of Dr. Schickle is as follows:

	Feet.	Feet.
Loam	1	1
Red clay	10	11
Blue clay	50	61
Quicksand	5	66
Hardpan	20	86
Shale	14	100
Sandrock	22	122

Genesee County.—The coal beds cross the northwest corner. The coal beds reported beneath Flint may be insignificant, possibly in the Grand Rapids series, though I think that it is absent here, but the following record is clearly well within the coal measures, and is authenticated by samples:

Flushing, 300 feet west of Flint River, on N. W. $\frac{1}{4}$ of Sec. 15, T. 8 N., R. 5 E. Drillers, Deland and Robinson. Reported by E. G. Goodell.

Sept. 8 and Nov. 14, 1898.

	Feet.	Feet.
Surface sand	15	15
Clay with streaks of gravel.....	32	47
Quicksand	2	49
Hardpan clay (till).....	2	51
"Slate" shale	2	53
Slate	15	68
"Slate"	9	77
Sandrock	9	86
Black slate (bituminous represents a coal horizon probably)	1	87
Fire-clay	3	90
Sandrock	4 $\frac{1}{2}$	94 $\frac{1}{2}$
"Slate" shale	4	98 $\frac{1}{2}$
Dark shale	8 $\frac{3}{4}$	107 $\frac{3}{4}$
Shale	20 $\frac{1}{4}$	127 $\frac{3}{4}$
Coal and black soft slate. This coal is probably lower than the Verne coal, and in varying thickness is quite persistent in the region	$\frac{1}{2}$	128
Sandrock	3	131
Shale	21	155
Hard shale	27	182
Hard shale	28	210
Slate with pyrite	6	216

Coal has also been dug in the shale pits of the Saginaw Clay M'f'g Co., near the S. W. corner of Sec. 22,* and is also said to outcrop on the river bank near the northeast corner of Sec. 4, of the same township. In the township north of Montrose a coal mine was started by a slope at Elk, but failed. Similar strata occur on Sec. 26, and appear to belong near the horizon of the Verne coals.

The seams of coal so far as at present explored, appear to be persistent but of varying thickness.

A good seam is said to have been discovered by Martin G. Hope at East Thetford to the northeast, 140 feet deep.

*See Part I of this volume, and also the analysis of the same.

At the residence of F. E. Holliday, Eighth St., Flint, eight inches of coal are said to have been found at 90 feet.

Eight feet of coal were reported at 87 feet deep on the place of Mrs. Mary Conger, Sec. 3, and nine feet in a later well, but the wells were for water and the presumption is that most of it was black shale.

It appears probable that in this county the coal is confined to the northwest of a line from Fostoria to Durand and that the coal probably occurs at less than 250 feet depth.

The record of the Oak Grove mineral well, Sec. 7, T. 7 N., R. 7 E., is reported as follows:

Casing	39'	39'
Sandstone	79'	118'
Coal	4' 4"	122' 4"
Sandrock	15'	137' 4"
Slate	60' 9"	198' 1"
Sandrock	67' 6"	265' 7"

Barry County.—There has been quite a little talk of coal in this county, and the Thornapple Coal and Oil Co. formed. The coal appears, however, to be all drift coal. For instance, about 800 paces N., 1600 W., in Sec. 6, T. 2 N., R. 7 W., in the valley of High Bank creek the following section was exposed:

	Feet.	Feet.
Till and beneath it stratified clay.....	15	15
Quicksand	20	35

with fragments of coal quite abundant at the bottom. Underneath is clay and then quicksand is said to recur, and the occurrence of clay capping the hills over sand is quite common.

The abundance of coal in the drift indicates that coal seams are not far off, but the Nashville water-works wells are said to go through about 100 feet of sand and gravel, 40 feet of clay, and the balance 115 to 125 feet in limestone rock, though another less reliable report says that they go through sandrock down to 300 feet. Bedrock here then will be the Eocarboniferous (Upper Grand Rapids) limestone, but there may be a chance for coal to the north.

Eaton County.—At the south side of the county the record of importance to add is the following of a mineral well by L. J. Lincoln at Eaton Rapids. The first 116 feet are undoubtedly in the coal measures, and the well seems to pass into the Parma or Grand Rapids group below. Lincoln's records rarely show coal, and the unintelligible P. K. slate (poor coal) appears in a place where older

records report coal. Six miles southeast of Eaton Rapids, good coal is said to have been met.

T. 1 N., R. 3 W., Eaton Rapids:

Character.	Thickness of stratum. Feet.	Total Depth. Feet.
Old gravel	22	22
Sand gravel	5	27
Shale rock	10	37
Shale rock	30	67
Shale rock	28	95
P. K. slate (?).....	7	102
Fire-clay	14	116
Sand and (?)	43	159
Water sand	20	179
Gray rock	2	181
Lime rock	3	184
Mineral rock	10	194
Sandrock	11	205
Water rock	1	206

Farther north, close to the county line a core drill proved the sandstone on Van Osdall's farm N. E. $\frac{1}{4}$ of Sec. 25, T. 3 N., R. 3 E., where a quarry was projected. For 75 feet it was all sandstone. From 14 to 39 feet the samples show coarse white sandstone. Above this are slaty streaks, and at 7 to 9 feet are brown blotches, apparently pebbles of FeCO_3 , such as occur in a sandstone over the coal at Williamston. The sandstone outcrops in the river near by.

About half-way down the river to Lansing, near Milletts, there have been explorations from an early date. A shaft for coal on the farm of Mr. Minie, Sec. 35, was put down in 1858 to 1859.

A section is given by Winchell, 1860 report, p. 124; see also Rominger III, p. 130, as follows:

Surface	5'	5'
Fire-clay, soft	2' 8"	7' 8"
Coal	2' 3"	9' 11"
Clay somewhat bituminous	4' 3"	14' 2"
Coal	1' 11"	16'
Fire-clay, white and hard	5' 8"	21' 9"
Argillaceous shale	16' 2"	36' 11"
Coal	0' 8"	37' 7"
Argillaceous shale with some pyrite.....	12'	49' 7"
Sandrock	4' 2"	53' 9"
Coal	4' 1"	56' 10"

On the other hand, a well on the farm of W. R. Locke on the same section 35, T. 4 N., R. 3 W., drilled in 1899 for Mr. W. O. Smith (Alt. 875) is reported as follows:

	Feet.	Feet.
Drift	?	
Fire-clay	?	16
Shale	15	31
Coal	2	33
Shale?	17	50

Some Ohio people are also said to have drilled here.

Two reasons for abandoning the early explorations are given—

that there was not enough roof, and that it was not thick enough to pay. Both may be correct, the one applying to the coal less than 20 feet down, the other to the lower coals, though if there were really four feet of coal at 56 feet it is hard to understand why it could not be successfully worked.

Making allowance for exaggeration, however, it still appears that in the first 60 feet are two or three coals, and only four or five miles away, in the next county, coal is found near the surface in some of the Lansing wells, and is said to have outcropped beneath some blue shale which lay below the sandstone quarry in the rapids of the Grand River, obliterated by the dam at North Lansing, a mile and a half up stream from Lansing. Within the county we find at Grand Ledge a similar section, where coal has been worked since 1839. The best section is exposed in the clay pits of the American (Grand Ledge) Sewer Pipe Co., about 1100 paces north, 500 west of the southeast corner of Sec. 3, T. 4 N., R. 4 W., as follows:

	Feet.	Feet.
Decayed sandstone	3	
Shale with streaks of FeCO_3	4	7
Black shale, coaly (Upper Rider).....	1	8
White shale, best sewer pipe clay, bounding line with next formation below undulating as if this is an alternation of the layer below (See analysis in Vol. VIII, Part I.)	2	10
Blue shale with <i>Sphenophyllum obovatum</i> and nodules of FeCO_3 , with ZnS and FeS_2	4	14

Black shale passing at east end into five inches of coal and thickening in Boyle's shaft, not far off into from 18 inches to 24 inches, apparently visible as a thin seam 4 inches or so thick, 12 feet above the main workings of C. Hodge, which are in a ravine just west.

This is also said to be the coal mined in the Pratt mine just over the county line in Clinton county on the west bank of Grand River where it is at times 30 inches thick. Harder than, and not so brittle as the next lower seam, with greater irregularity in thickness apparently. The black shale directly above contains a delicate compressed lamellibranch (cp. *Anthracosia* or *Macrodon carbonaria*).

The coal was also mined some years ago at a profit in a shaft by Irving Jenkins, close to the Boyle shaft. Farther southwest the whole series seem to pass into sandstone, and in another shaft the coal was found to be so split up as to be unworkable.

	Feet.	Feet.
Upper Verne	1	15
Under this coal come black and white flaking sandstones (Ashley calls them fake) sometimes quite massive, as at Hodges' drift and varying much in thickness,—usually from 10 to 20 feet thick.....	20	35
Next we have a lower seam of coal, Analysis (Ea) more uniform in thickness, more brittle than the upper coal, and known locally as the 18 inch or sandstone coal, quite persistent, worked by Arnold and R. F. Wilkinson (Lower Verne).....	1' 6"	36' 6"
Below this comes the sandstone again.		

The lithological character of the section is quite variable, as well as the thickness of the different members. In Boyle's mine in one place the two coals approach so near that in taking up the foot

of the upper coal the lower is exposed. In fact, in the bluff of the river to the east of the clay pit they appear within 7 feet of each other, the upper only 9" thick, the lower 15".

In a clay pit on the N. W. $\frac{1}{4}$ of Sec. 11 under a heavy cross-bedded sandstone 15 feet thick comes a few inches of shales, from which most of the specimens come on which the correlation with the Mercer group was based by White.*

Then about two feet of coal rolling and dipping in one place to N., in another 10° to 15° to E.

Then 3 feet of fire-clay and shale. The coal here I take to be the upper seam.

One or the other of the coals may be traced up the river through the town, having been worked according to reports under the grist mill (upper coal). In the Island House (Mudge) well 18 inches of coal is said to have been found near the top, though Rominger reports one at 65 feet. Below for 100 feet or more and in a deeper well put down by Dr. Ball, near the river and the east line of Sec. 11, T. 4 N., R. 4 W., only sandstone is reported. From the general succession as well as the fossils associated and the character of the coals, we seem to have here an Upper Rider, the Upper Verne and the Lower Verne coals. The basal series of sandstones do not appear to be split by the coals of the Saginaw series.

The coals exposed in the deep cut of Grand River probably extend clear across the county, though covered with a heavy layer of drift, through which little or no drilling has been done. When we go south, however, into the valley of the Thornapple, exposures occur around Chester of a coal seam, at most three feet thick, as described by Rominger.†

Samples from a recent boring near Carlisle on the S. E. $\frac{1}{4}$ of Sec. 24, T. 2 N., R. 6 W., are as follows:

Surface, blue clay broken at the bottom.....	39'	39'
Black shale with thin seams of coal,—a coal horizon	11'	50'
White shale, under clay.....	3'	53'
Dark shale with some FeCO ₃	2' 6"	55' 6"
Black and white shale	2' 6"	58'
Blue shale	10"	58' 10"
White sandstone	1' 2"	60'
Black and white shale	6' 6"	66' 6"

*Page 44.

†Vol. III, p. 131.

We have coal measures, obviously, and it would seem worth while to go somewhat deeper, though the record of the deep well at Charlotte is not encouraging.

In the southwest part of the county around Bellevue the Eocarboniferous limestone outcrops and no coal is to be expected, and it is probable that the productive coal measures of the county are rather thin everywhere, with no indications of coal seams below the Verne (Grand Ledge) seams, except perhaps in the extreme northeast.

Ingham County.—Many records from the neighborhood of Williamston are given in Vol. III of our reports.*

In a general way it is said that there is a 44 inch bed of coal, outcropping, or but a few (13) feet below surface, so having no roof. About 48 feet below the surface is a second seam.

Rominger summarizes them as follows: "The above experiments show a uniform distribution of a coal seam about 3 feet in thickness over this whole district. Its position is often too superficial, without a proper roof, for advantageous mining. In nearly all the borings two seams of coal are found, of which the upper one is generally too narrow to be of practical value. The two seams are separated by from 15 to 20 feet of intermediate beds."

One of the exposures of the coal measure shales, etc., is shown on the farm of C. M. Phillips, Sec. 28, T. 4 N., R. 1 E., near which were some of the earliest coal diggings. Nodules of FeCO_3 are common, and the dump of the abandoned coal mine shows numerous fragments of a conglomerate with a white sandstone matrix and numerous pebbles of FeCO_3 .

The two coal seams to which Rominger refers I take to be the Verne seams, and they are associated with black shales containing similar marine animals.

The following records, which I owe to Mr. W. T. Chappell, show that the Saginaw seam exists below.† The J. H. Somers Co. also found some coal down at 249 feet.

Records for W. T. Chappell, by O. A. Shadbolt, near Williamston, Ingham county:

*Part I, pp. 130, 135, 136. See also Lansing, "Exposition concerning Mineral coal in Michigan," Detroit, 1854.

†See also Michigan Miner, Vol. 3, No. 7, p. 16, June 1, 1901.

No. 1, S. W. $\frac{1}{4}$, Sec. 34, T. 4 N., R. 1 E.

Yellow sand and clay.....	12'	12'
Fine sand.....	8'	20'
Blue clay.....	25'	45'
Hardpan.....	21'	66'
Blue shale.....	23'	89'
Fire-clay.....	10'	8" 99' 8"
Blue slate.....	8'	107' 8"
Coal (Upper Verne?).....	4"	108'
Black slate.....	8'	116'
Gray slate.....	7'	123'
Black slate.....	8'	131'
Fire-clay.....	3'	134'
Black slate.....	4'	138'
Fire-clay.....	7'	145'
Black slate.....	5'	150'
Coal (Lower Verne?).....	6"	150' 6"
Sandy shale.....	6'	156' 6"
Black slate.....	7'	163' 6"
Sandy shale.....	8'	171' 6"
Black slate.....	1'	173'
Gray slate.....	24'	197'
Black slate.....	4'	201'
Sandy shale.....	3'	204'
Black slate, strong.....	9'	213'
Coal (Saginaw?).....	2'	215' 6"
Fire-clay.....	6'	221' 6"
Gray slate.....	43'	264' 6"
Black slate.....	10'	274' 6"
Gray slate.....	14'	288' 6"
Black slate.....	2'	291'
Hard rock.....	2'	293' 6"
Black slate.....	11'	304' 6"
Sandy shale.....	2'	307' 6"
Sandrock.....	3'	310'

No. 2, N. E. $\frac{1}{4}$, Sec. 3, T. 3 N., R. 1 E. About 40' lower than No. 1,
June 3, '99.

Sand.....	12'	12'
Clay.....	6'	18'
Sand.....	2'	20'
Hardpan.....	7'	27'
Black slate.....	3'	30'
Fire-clay.....	22'	52'
Soft black slate.....	7'	59'
Coal (Upper Verne?).....	1'	60'
Fire-clay.....	21'	81'
Gray slate.....	8'	89'
Black slate.....	26'	115'
Coal (Lower Verne?).....	6"	115' 6"
Fire-clay.....	9'	124' 6"
Sandy strata.....	29'	153' 6"
Gray slate.....	1'	155'
Sandrock.....	2'	157'
Sandy shale.....	8'	165'
Sandrock.....	11'	176'
Gray shale.....	4'	180'
Sandrock.....	3'	183' 6"
Sandy shale.....	6'	189' 6"
Sandy fire-clay.....	1'	191'
Gray slate.....	35'	225'
Sandy shale.....	13'	239'
Gray slate.....	7'	246'
Black slate.....	11'	257'
Coal (Saginaw?).....	1'	258' 4"
Fire-clay.....	3'	261' 4"
Sandrock.....	4'	265' 10"

No. 3, N. W. $\frac{1}{4}$ of Sec. 33, T. 4 N., R. 2 E. Leasia farm, 160 rods
W. of N. W. of No. 1 and perhaps 10' higher.

Clay.....	12'	12'
Sand.....	13'	25'
Clay.....	25'	50'
Hardpan.....	8'	58'
Clay.....	12'	70'
Hardpan.....	5'	75'
Sandrock.....	15'	90'
Black shale.....	10'	100'
Coal (U. Verne?).....	1' 4"	101' 4"
Fire-clay.....	2'	103' 4"
Gray shale.....	4'	107' 4"
Black shale.....	4'	111' 4"
Gray slate.....	2'	113' 4"
Fire-clay.....	2'	115' 4"
Black slate.....	6'	121' 4"
Sandy fire-clay.....	6'	127' 4"
Gray slate.....	5'	132' 4"
Fire-clay.....	2'	134' 4"
Gray slate.....	13'	147' 4"
Black slate.....	14'	161' 4"
Sandrock.....	2'	163' 4"
Fire-clay.....	3'	166' 4"
Coal.....	6"	166' 10"
Fire-clay.....	4' 6"	170' 4"
Black slate.....	6"	170' 10"
Coal.....	6"	177' 4"
Fire-clay.....	6'	177' 4"
Sandy shale.....	40'	217' 4"
Black slate.....	3'	220' 4"
Sandrock.....	10'	230' 4"

These wells of Shadbolt may be compared with the following one of L. J. Lincoln, who, it will be noticed, probably did not distinguish the coal from the slate. We see that the coal measures continue down anyway to 362 feet, and the black slate from 323 to 345 feet may very easily be the same black, coal-bearing horizon that was struck in No. 1 at 289' to 305'.

N. W. corner, Sec. 33, T. 4 N., R 1 W., Meridian township:

Character.	Thickness of stratum. Feet.	Total Depth. Feet.
Old well.....	23	23
Soft clay.....	17	50
Clay and hardpan.....	40	90
Beginning of coal measures—		
Shale.....	15	105
Slate.....	95	200
Slate to sand.....	20	220
Sand and water.....	27	247
Slate.....	34	281
Shale.....	22	303
Black slate.....	20	323
Soapstone.....	22	345
Fire-clay.....	17	362
Light slate.....	35	397
Beginning of Parma sandstone? and transition to Eocarboniferous limestone—		
Light sandrock.....	15	412
Lime rock.....	16	428
Sand.....	11	439
Fine sand.....	10	449
Fine sand.....	7	456
Fine sand.....	24	480
White sand.....	19	499
Sand to hard rock.....	10	509
Hard lime.....	5	514

Coming about an equal distance northwest to the Agricultural College, on Sec. 18, T. 4 N., R. 2 W., we have the old well put down by L. J. Lincoln in 1887, of which there were 15 bottles of samples taken—and 13 now left at the Agricultural College. By their means we may correct Lincoln's log and obtain the following record:

RECORD.

Quicksand	11	11
Clay (10-20)	9	20*
Hardpan, i. e., till, dark clay and sand.....	17	37*
Black shale	3	40*
(Very dark with bits of coal, other wells near by are said to have struck coal at this level).		
Fire-clay	2	42
Fire-clay and shale	42	84*
(50-76, light clay shale).		
Sandrock	118	202*
(84-155, light).*		
(152-162, sandy clay with dark bits).*		
(162-180, white sand with coal 10% or so).*		
(180-187 white sand, coarse, with coal).*		
(187-218) fine sand with iron rust, probably representing pyrite and black specks).		
Shale (?)	23	225
Sandrock	25	250*
(255-308, very fine, blue sandrock).		
Shale	40	304*
(265-308, very fine, blue sandrock)		
Sandrock	29	333*
(308-329, white sand).*		
Shale	16	349
Sand	2	351

Another well was put down near by in 1899, by Elmer E. Strobe of Mason, Mich., of which the State Geological Survey have a set of samples.

Sec. 18, T. 4 N., R. 1 W., depth (p. 17 of 1900 report) 345', cost \$700.00:

Sand, fine.....	8'	Comparison with other wells.
Gravel, fine.....	21'	
Brown smooth clay.....	2'	
Dark blue shale.....	14'	No. 1, 37-84 with coal.
First water here.....	37'	
Fine grained white sandstone.....	37'	
Coarse sandstone, white.....	43'	125'
Flow of water.....	35'	160'
Sandy shale.....	12'	172'
Coarse white sandstone, conglomerate at 185 feet.....	44'	216'
Yellow sandstone.....	14'	230'
Sandstone and coal.....	9'	239'
Coarse pyritic sandstone.....	16'	255'
Dark sandy shale.....	9'	264'
Sandstone and siderite, very hard.....	12'	276'
Sandstone and coal.....	4'	280'
(Good clean samples, said to be a few inches thick) at 280 feet.		
Shale, or fire-clay.....	6'	286'
Smooth shale.....	39'	325'
Water sandstone?.....		343'

*Represented by samples; descriptions in parentheses are from samples and not from Lincoln's records.

In Carpenter's paper on the use of this water as a boiler water the depth is given as 265 feet. (Trans. Am. Soc. Mich. Engineers, XI, p. 239), probably a misprint for 365 feet. Various reports made the well from 343 feet to 470 feet deep. Originally, however, it seems to have been 365 feet deep, though the report of the state board makes it 343 feet deep, cost \$1,000.

In these two wells a big body of sandstone with some streaks of coal in it, separates a lower and upper body of shales.

Passing two miles and a half farther to the Industrial School in the E. $\frac{1}{2}$ of the N. W. $\frac{1}{4}$ of Sec. 15, which stands about 20 feet higher, we find the record:

	Feet.	Feet.
Clay and gravel.....	36	36
Sand and gravel	5	41
Sandy hardpan	4	45
Lake sand and gravel.....	37	84
Clay, sand and gravel.....	16	100
Lake sand and gravel	1	101
Soft sandrock	3	104
Hard fire-clay	4	108
Soft white sandrock	13	121
Soft sandy fire-clay.....	15	136
Hard sandrock	119	255
Winchell says from 101 to 255 is sandstone "first water."		
Hard fire-clay alternating with beds of sand-rock variable in color from whitish to blue..	64	319
Cherty lime	1	320
Gray lime	4	324
Sandy fire-clay mixed with seams of hard rock	61	375
Soft sandrock	37	412
Hard gray limestone	2	414
Soft white sandrock	15	429
Blue limestone	1	430
White fire-clay	1	431
Sandrock	4	435
Fire-clay with iron pyrites.....	50	485
Soft sandrock	5	490
Blue limestone	16' 6"	506' 6"

The difference in thickness of drift corresponds practically to the difference in elevation of this and the Agricultural College wells, and we plunge at once into a sandy series which culminates about 255' down. This record shows no coal, but King and Wigant say they found at the North Lansing railway station of the Pere Marquette:

	Feet.	Feet.
Surface with 14 feet of gravel.....	55	55
Sandrock with 6 inches of coal at 62 feet....	13	73

Coal is also reported from a number of wells near the School for the Blind, e. g., at Christopher's, 434 Willow St., in the bed of the river, and at 430 Willow St. there is said to be 3 feet of coal; at Shadoin's, 612 Saginaw St., 5 feet thick, the section being as follows:

	Feet.	Feet.
Clay	65	65
"Soaprock" shale	14	79
Coal	5	84
Sandrock	26	110

at Watson's, 606 Saginaw St., 1 foot thick. Hon. J. Robson, 321 Walnut St., is said to have found 4 feet of coal in his well.

At the corner of Pine and Kilborn Sts. there is said to be

	Feet.
Casing	58
Black rock	2
Coal	5

At 501 Pine St., H. R. Cadwell, there is said to be 4 feet of coal at 75 feet. So that the upper coal horizons must be fairly persistent near the bedrock surface, perhaps too near to work.

Still, the coal is not continuous, as we see from a record at 318 Jefferson Ave.

	Feet.	Feet.
Red clay	16	16
Blue clay free from stones	10	26
Blue quicksand, water rises to 12 feet from the surface	6	32
Water sand	8	40
Blue clay or soaprock	25	65
Probably sandrock	11	76

When we turn to the southeastern part of Lansing we find less trace of coal.

Lincoln's record of the Condensed Milk Company's well is as follows:

	Feet.	Feet.
Sand and gravel	16	16
Sandrock	15	31
Fine sand	5	40
Water sandrock to shale	28	68
Slate	10	78
Light slate (probably the fire-clay below the coal horizon) and sand	17	95
Fine sandrock	22	117
White sandrock	21	138
Light sandrock	20	147
White sandrock	17	164
Gray sandrock	18	182
Fine sandrock	5	198

This is not far from the Industrial School, but a good deal lower, as is shown by the thinness of the drift, for the rock surface appears to be pretty flat. In fact, in the abutments of the Michigan Avenue bridge, across the Grand River, near this well, the sandstone was struck and slabs of it are preserved at the Agricultural College. Close to the bridge, too, are the water-works wells—those which are used meeting rock at about 36 to 46 feet and ranging mainly 150 to 160 feet deep. But there is one deep one at the S. W. corner of the lot, whose record, Feb. 17, 1896, from the State Republican, is as follows:

	Feet.	Feet.
Surface to rock	46	46
First eight feet soft, porous, coarse sand-rock	30	76
Hard clay	2	78
Finest sandrock, plenty of water.....	100	178
Fire-clay	2	180
Blue sandrock	30	200
Yellowish sandrock, plenty of water.....	30	230
Fire-clay	2	232
Grayish rock	30	262

Gold particles were said to be found, probably pyrite or bronzy mica.

	Feet.	Feet.
Fire-clay	15	277

At 275 feet was a rock "as hard as flint, and the sand pump yielded a metal that resembled gold," i. e., pyrite.

	Feet.	Feet.
White sandstone porous.....	25	302
"Granite" stone, very hard.....	25	327
Hard white rock, with big flow of water rising within 5 feet 9 inches of surface, and much above the water.....	13	340

Probably through this part of the town the sandrock is the surface rock, as indicated by the following wells:

Lantz' well at the laundry, 120 feet deep, 60 feet to 80 feet to bedrock, Piatt's, behind the Downey House, 58 feet to rock and white sandstone down to 112 feet (1901).

The Downey House well recorded by Winchell* thus:

	Feet.	Feet.
Sand	4	4
Light blue clay	10	14
Sand and clay	4	18
Sand and gravel	37	55
Sandstone	7	62

continued to 500 feet, according to Rominger, or 740 feet, some say, when it became too mineral in taste and is now plugged at about 70 feet. The Hollister Block well is about 150 feet deep. The city water-works test well, now flowing close to the junction of the Cedar and Grand rivers, on Hazel street, which Mr. Stephenson tells me was mainly clean white sandrock, was 340 feet deep, and six blocks west, at the corner of Isaac and Chestnut streets, is a similar flowing well 365 feet deep.

Southwest of Lansing, in the bed of the Grand River, was a sandstone quarry, and Mr. George H. Pratt informs me that in quarrying under the sandstone a shale with coal was exposed.

Mr. Lincoln also put down a large number of wells around

*Am. Ass. Adv. Sci., 1875, B., p. 81.

Mason. As we have seen, he does *not* distinguish the coal from black slate, but from the following records we see that there are one or two coal horizons in the first hundred or hundred and fifty feet,* and one considerably lower. Somewhat below 300 feet we pass into the Eocarboniferous limestone series, so that the strata lie as deep here as 10 miles north.

Wherever black slate, brittle slate and shale appear in his records there may be more or less coal.

A heavy sandstone quite frequently separates the upper coal horizons which we may correlate with the Verne, from the lower, which we are inclined to correlate with the Saginaw as we did at Williamston, with which it seems to connect.

There is no close parallelism but merely an epoch of somewhat more disturbed condition and coarser sediment which we seem also to trace through to the north.

T. 2 N., R. 1 W., S. W. part Section 3. Record No. 20:

Character.	Thickness of stratum. Feet.	Total Depth. Feet.
Sandrock	13	13
Sand and water-pack sand	22	35
Blue sand and gravel	5	40
Shale	7	47
Shale and hard spots	5	52
First hard rock at.....	5	52
Shale	6	58
Soft sandrock	2	60
Water and sandrock	5	65
Water and hard rock	2	67

N. E. corner of N. E. quarter of section 8, block 4, Mason, Vevay township:

Character.	Thickness of stratum. Feet.	Total Depth. Feet.
Slate	13	22
Light slate	19	35
Slate	21	54
Slate to sandrock	45	75
Gray sandrock	29	120
White sandrock	30	149
Sand to slate	18	179
Black slate	29	197
Fire-clay	15	226
Light slate	13	241
Lime and slate	8	254
Soft lime	6	262
Light slate	30	268
Hard rock	4	298

*See Rominger, Vol. III, Part I, p. 130.

Mason City water-works, on city lots:

Character.	Thickness of stratum. Feet.	Total Depth. Feet.
Hardpan and clay	15	15
Gravel and sand	5	20
Black shale	3	23
Light shale	15	38
Water sandrock	26	64
Water sandrock	34	98
Hard sandrock	22	120
Softer sandrock	10	130
To slate	11	141

Mason City water-works well, south of plant, No. 1: Record No. 5.

Character.	Thickness of stratum. Feet.	Total Depth. Feet.
(Old well?)		69
Fine sand	14	81
Sand to hard rock	4	85
Gray sandrock	6	91
White sandrock	20	111
Sandrock	10	121
Blue sandrock	11	132
White sandrock	7	139

Mason City water-works well, N. E. part block 43, Record No. 7: T. 2 N., R. 1 W.

Character.	Thickness of stratum. Feet.	Total Depth. Feet.
Gravel	2	3
Water gravel	1	5
Gravel and sand	14	20
Hardpan	8	28
Hardpan and shale	4	32
Fire-clay	2	34
Black slate or shale, coal horizon.....	10	44
Lighter shale	10	54
Hard rocks	2	56
Sand and water	31	87
Sandrock	13	100
Slate	12	112
Sandrock	6	118
Light shale	6	124
Light sandrock	5	129
Shale	2	131

Mason City water-works well, Lot 11, block 15; Record No. 8:

Character.	Thickness of stratum. Feet.	Total Depth. Feet.
Shale rock	11	14
Slate and sandrock	22	36
Sandrock	22	58

Record No. 9:

Character.	Thickness of stratum. Feet.	Total Depth. Feet.
Clay and sand	6	6
Sand, clay and gravel	25	31
Hard rock	3	34
Sandrock	7	41
White rock	14	55
Slate and sandrock	11	66
White sandrock	24	90
Gray sandrock	10	100
Sandrock	31	131
Fine sandrock	19	150
To slate	5	155

Mason City water-works, city lots, Record No. 10:

Character.	Thickness of stratum. Feet.	Total Depth. Feet.
Sand, gravel and hardpan	9	14
Shale and slate	10	24
Light slate	26	50
Sandrock	15	65
Water rock	2	67

Record No. 11:

Character.	Thickness of stratum. Feet.	Total Depth. Feet.
Sand and gravel	9	13
Shale	8	20
Sand slate	5	25
Slate	10	35
Slate	12	47
Sandrock	19	66
Fine sandrock	33	99
White sandrock	60	159
Blue sand and putty (soft clay)	13	172

S. W. corner block 1:

Character.	Thickness of stratum. Feet.	Total Depth. Feet.
Old well	70	70
Sandrock	35	105
Sand to hard rock	17	122
Very hard sandrock	4	126
Sandrock	68	194

N. W. corner block 12, Mason:

Character.	Thickness of stratum. Feet.	Total Depth. Feet.
No record	38	38
Sand and gravel	18	54
Shale and hard rock	7	61
Black slate	8	69
Light slate	36	105
Sandrock	27	132
Slate	18	212
Black slate	21	233
Black slate to sandy spots	13	246
Slate	28	274
Light slate	14	288
Fire-clay	33	321
Hard rock	6	327
Soft to hard rock	13	340
Water sandrock	45	385

T. 2 N., R. 1 W. N. E. part block 52, city:

Character.	Thickness of stratum. Feet.	Total Depth. Feet.
Black shale	33	20
Light shale	17	53
Sand and water rock	20	70
Slate	14	90
Sand and water	61	104
Sandrock	31	165
Blue sand	6	196
Sandrock	10	202
Light slate	8	212
Light slate to fire-clay	10	220
Fire-clay	9	230
Fire-clay to slate	10	239
Slate	8	249
Slate to sand	3	257
Sand and water	8	260
Light slate	3	268
Fire-clay	12	271
Light slate	6	283
Dark slate	5	289
Light slate	6	294
Fire-clay with hard spots	17	300
Water rock	49	317
Firm sandrock	20	366
Limerock	5	386
		391

T. 2 N., R. 1 W. S. W. part of block No. 7, Steel and Holt's
Addition:

Character.	Thickness of stratum. Feet.	Total Depth. Feet.
Sand	23	23
Sand and hardpan	10	33
Black slate	15	48
Slate rock	7	55
Sand and slate	$\frac{1}{2}$	60 $\frac{1}{2}$
Fine sand and slate	50	110 $\frac{1}{2}$
Blue	23	133 $\frac{1}{2}$
Water rock	27	160 $\frac{1}{2}$

Mason City water-works well, N. E. part block 43:

Character.	Thickness of stratum. Feet.	Total Depth. Feet.
Gravel	2	5
Water gravel	1	6
Gravel and sand	14	20
Hardpan	8	28
Hardpan and shale	4	32
Fire-clay	2	34
Black slate or shale	10	44
Lighter slate	10	54
Hard rock	2	56
Sand and water	31	87
Sandrock	13	100
Slate	12	112
Sandrock	6	118
Light shale	6	124
Light sandrock	5	129
Shale	2	131

N. W. corner, block 18, city, record No. 21:

Character.	Thickness of stratum. Feet.	Total Depth. Feet.
To gravel and sand		8
Gravel and sand	2	10
Blue clay	8	18
Hardpan	85	103
Hard limerock	8	111
Slate rock	10	121
Dark flakes	2	123
Hard limerock	44	167
Blue sandrock	10	177
Sandrock	11	188
Fine sandrock	14	202
Hard sandrock	3	205

Block 24, lot 3, Mason, Record No. 27:

Character.	Thickness of stratum. Feet.	Total Depth. Feet.
To gravel	21	21
Clay	13	40
Blue clay	10	50
Fire-clay and light slate	24	74
Hard sandrock	15	90
Fine sandrock	14	104
Sand and water rock	9	113

T. 2 N., R. 1 W. E. half of Sec. 9, Vevay township:

Character.	Thickness of stratum. Feet.	Total Depth. Feet.
Clay	10	10
Hardpan and gravel	18	28
To shale	2	30
Shale	2	32
Shale and slate	12	44
Slate	82	126
Sand and slate	69	195
To shale	13	208
Black shale	18	226
Light shale to hard limerock	15	241
Limerock	3	244
Light clay	23	267
Fire-clay to slate	15	282
Shale	15	297
Shale	27	324
<i>Top of Mesozoic (?)</i>		
Sand and hard rock	19	343
Sandrock	45	388

T. 2 N., R. 1 W., S. W. corner Sec. 14:

Character.	Thickness of stratum. Feet.	Total Depth. Feet.
Clay and hardpan	15	15
White clay and lumps of coal	4	19
White clay and sandstone	15	34
Light shale	23	57
Dark slate	10	67
Black shale	2	69
Slate and coal	3	72
Light slate	12	84
Slate and lime	6	90
Light slate	3	93
Fire-clay	2	95
Black slate, brittle	5	100
Sandrock	1	101
Light slate	10	111

N. E. corner Sec. 20, Vevay township, Record No. 32:

Character.	Thickness of stratum. Feet.	Total Depth. Feet.
Old well		42
Sand to gravel	21	63
Hardpan and sand	3	66
To rock	36	102
Hardpan	8	110
Slate	9	119
Light slate	9	128
Light slate and sand	17	145
Hard sandrock	8	153
Water rock	5	158
Sandrock	13	171

T. 2 N., R. 1 W., S. W. corner N. W. quarter Sec. 22:

Character.	Thickness of stratum. Feet.	Total Depth. Feet.
Old well		62
Black slate	21	83
Black slate to sand	30	123
Sand to slate	20	143
Very hard rock	20	163
Blue sand	29	192
Fire-clay	2	194
Light slate	13	207
Dark slate	15	222
Light and dark slate	13	235
Light and dark slate	12	247
Light and dark slate	18	265
Fire-clay	11	276
Light shale	10	286
Light shale	10	296
Light shale	9	305
Light shale	9	314
Eocarboniferous limestone—		
Hard lime	4	318
Hard rock	16	334
Sand and lime	11	345
Sand and water rock	22	367
Very hard	1½	368
Lime	4	372
Sand and water	11½	384
Water	19	403
Water rock	6	409

S. W. corner Section 27 (Eden), Vevay township, Record No. 33:

Character.	Thickness of stratum. Feet.	Total Depth. Feet.
Old well		9
Clay	18	27
Hardpan	11	38
Sand and water rock	14	52
Pure clay and shale	8	60
.....	19	79
Sand	7	86
Hard sandrock	2	88
Water rock	16	104

28—Pt. II

T. 2 N., R. 2 W.; N. E. corner of S. E. quarter, Section 23, Aurelius township, Record No. 26:

Character.	Thickness of stratum. Feet.	Total Depth. Feet.
Old well	33	
Hardpan and rock	5	38
Slate and sand (stones).....	15	53
Soap stone and clay	7	60
Slate	23	83
Sand (stone)	12	95
Slate and sand (stone)	30	125
Sand (stone) and shale	9½	134½

Coal is reported from T. 1 N., R. 2 W.

Coal has been found on the farm of J. R. Potter, Sec. 6, T. 2 N., R. 2 E., by J. McDowell at a depth of 25 feet. It is said to be three feet thick. There is no doubt that practically the whole of the county is underlain by the coal measures.

Livingston County.—The coal measures may cross the west part of this county, but the following record, by L. J. Lincoln, at Howell, can be best interpreted by supposing that the shales are in the same series as at Durand, and that perhaps some of the overlying sandstone or conglomerate was not distinguishable from the hardpan above. The bedrock first struck is probably the conglomerate at the base of the coal series, and the shales below are Lower Marshall and Coldwater.

Howell Condensed Milk Company's well, T. 3 N., R. 4 E.:

Character.	Thickness of stratum. Feet.	Total Depth. Feet.
Clay	5	30
Clay and gravel	19	35
Marl and sand	8	54
Pack sand	20	62
Pack sand to hardpan.....	17	82
Stony	14	99
Stony hardpan	5	113
Clay and hardpan	1	118
Hardpan	5	119
Quartz rock	48	124
Hard rock	4	172
Sandy	4	174
Sand and water	1	178
Fire-clay	19	179
Light slate	11	198
Sand and slate	18	209
Fine sand	5	227
Light slate	12	232
Light shale	16	244
Soapstone	19	260
Sand	10	279
Light shale	3	289
Black slate and brown shale.....	43	292
Brown shale, harder	79	335
Light shale	66	414
Slate	60	480
	10	540

Calhoun County.—The coal measures may extend a little way in

the extreme northwest part of this county in Lee, Clarence and Sheridan townships, and coal is liable to be found as far as they go, as shown by wells reported only three or four miles from Albion, and given in connection with Jackson county. There are reports of coal through a number of different people here, near Boyd's farm, Sec. 13 and Sec. 24, T. 2 S., R. 4 W.

The report of four feet of coal six miles south of Marshall must be an error.

Jackson County.—This county has been quite fully described by Winchell and Rominger.

The New Hope mine on the west side of Sec. 27, T. 2 S., R. 1 W., has been already described in connection with the analyses of its coal, A5 and A6.

The Trumbull Mining Co., already referred to, on page 106, lies in continuation of the old Woodville mine to the northwest on Sec. 24, T. 2 S., R. 2 W. This coal is said to be 3 feet thick about 80 to 125 feet down.

This is a rather narrow trough and ran out toward the Michigan Central track. Mr. Robert Gage has operated on the same coal on the Laverty farm at Woodville.

The National Mining Co. did some exploring for coal on the farms of Mrs. J. Watts and E. W. Barber, southeast of Jackson Junction.

The coal lies mainly, it will be noticed, northwest of Jackson.

Coal $3\frac{1}{2}$ feet thick was said to have been found on the Daniels farm, 2 miles west of the city, where, $\frac{1}{4}$ mile from the city limits, is said to be 80 to 100 acres of coal about 3' 3" thick, at a depth of 105 feet. It is to be exploited by the Central City Coal Mining Co.

Some records near the Calhoun county line, which I owe to Mr. W. T. Chappell are of interest.

Well on farm of A. Burns, $3\frac{1}{2}$ miles northeast of Albion, near L. S. & M. S. R. R., O. A. Shadbolt, driller:

Dry sand	20		
Wet sand	30		50
Clay	3		53
Black shale	3		56
Coal (Verne?).....	1'	4"	57' 4"
Black shale	4		61' 4"
Fire-clay	3		64' 4"
Sandrock	25		89' 4"
Hard rock (FeCO ₃ ?).....	2		91' 4"
Sandy fire-clay	6		97' 4"
Sandrock	98		195' 4"
Coal (Saginaw?)	0'	2"	195' 6"
Sandrock	5		200' 6"

On John Holmendinger's farm, $\frac{3}{4}$ mile away:

Sand	20	
Sandrock	27	47
Slate	6' 6"	53' 6"
Coal	0' 6"	54
Fire-clay	8	62
Gray slate	14	76
Hard rock (FeCO ₃ ?)	1	77
Sandrock	73	150
On Barnes' place—		
Sand	64	64
Sandrock	90+	154+

Thus it seems as though we have in Jackson county, as around Mason and Lansing, a heavy sandstone splitting the shaly coal-bearing series, with coal below sometimes as well as above. The upper series is probably that which has been mined and corresponds to the Upper Verne. In the deep wells, reported in Vol. V, the lower coal seams, the Saginaw, etc., have apparently dropped out, and the sandstones merge together as they seem to do southeast of Corunna also.

We notice, too, that most of the coal seems to lie west and northwest of the city, although one of the Emerson shafts at least was southeast. The Porter mine (Fig. 5) and other abandoned mines were right in the city. The Eureka was northeast.

The coal formation seems not infrequently to lie in hollows eroded out of the limestone which lies underneath.

For instance, southeast of the city, Poole and Emerson had a shaft in the valley, while the hill adjacent was capped with Eocarboniferous limestone on sections 12 and 13, T. 3 S., R. 1 W.

Moreover the wells near Albion just cited are considerably outside the line of strike of the Eocarboniferous limestone from Jackson to Bellevue.

INDEX TO PART II.

A.		Analyses—Con.	
Acetate of lime, made from peat	21	B 7 and B 8.....	95
American Chemical Society Committee.....	56, 62	B 10 and B 11.....	96
Age of coal fauna.....	42	C.....	97, 112
Agricultural College.....	21, 68, 209	D.....	97, 113
See also KEDZIE, CLARK,		D 1.....	97, 102, 106
WEIL.		D 4.....	92, 93, 98
Albee Coal Mine.....	95	D 5 to D 8.....	92, 93, 95, 96, 98
See VERNE COAL.		D 9.....	98, 102
Albion, coal near.....	219, 220	D 10.....	98
Alcohol made from peat.....	21	D 11.....	99
Allen, W. H.....	109, 119	E.....	101, 114
Alleghthonous Coal deposits.....	8	E 1.....	102, 106
Alma...30, 34, 36, 41, 122, 134, 161, 174		E 2=A 6.....	102
Amelith Shaft.....	23, 43, 45, 163,	E 3=D 9.....	98, 102
171, plate IX.		F.....	102, 114
Alpena County, blackshales of...27,		F 1.....	102, 104
77, 105		F 1 and F 6.....	96
American (Grand Ledge) Sewer		F 2.....	103
Pipe Co.....	98, 203	F 2 and F 3.....	104
Ammonia from coal...21, 63, 64,		F 5.....	103, 104
107, 108		F 6.....	103, 104
Analyses...20, 22, 51, 54, 57, 64, 86		F 7.....	94
89, 90, 106, 107, 108		F 8.....	97
A.....	110, 90 to 96	G.....	104, 115
A 1.....	89, 90, 102	G 3.....	104
A 2.....	91, 92, 108	G 4.....	77, 99, 105
A 3.....	89, 91, 92	G 5.....	77, 105
A 4.....	92, 103	G 6.....	94, 105
A 5.....	93, 104, 219	G 7.....	77, 105
A 6.....	94, 100, 101, 104, 219	G 8.....	77, 105
A 7 to A 10.....	96, 98, 106	H.....	105, 116
A 8 (B 8 and D 6).....	95	H 4.....	94
A 9.....	95, 103, 107	H 7 and 8.....	106
A 10.....	71, 96, 109	H 8.....	106, 107
A 11.....	96, 109	H 9, 10 and 11.....	107
A 12.....	96, 106	I.....	107, 117
B.....	97, 111	I 1.....	64, 89
B 1.....	106	I 2.....	89
B 4.....	92, 93	I 3 and 4.....	73, 108
B 6.....	94, 95	I 4 to 10.....	108
		I 11 to 12.....	109

- Analyses—Con.**
- J.....109, 118
- K.....109, 119
- Of peat.....117
- Of slack.....108
- Proximate.....62, 114
- Ultimate.....61
- Andrews, E. B.**.....36
- Annularia**.....47
- Anthracite**.....10, 17
- Antrim County**.....20, 27
- Arenac County**.....121, 158, 160
- Arkansas series**.....50
- Arnold mine**.....203
- Arthur, coal at**.....178, 179
- Artesian wells, danger of**.....129
- Ash**.....18, 19, 20, 57, 58, 85, 100, 101, 103
- Per cent of in coals. (See ANALYSES.).....19, 77, 78
- Ashley**.....40, 174
- Ashley, Geo. H.**.....49, 203
- Auburn**.....122
- Augusta limestone**.....29
- Autochthonous coal**.....7
- Avicula acosta**.....42
- B.**
- Bain, H. F.**.....2, 7, 32, 34, 35, 49
- Banger Township**.....168, 171
- Bar of sandstone in coal**.....127, 128, 182
- Barnard Coal Co., limited**.....180, 182
- Barnard Coal Company**.....179, 180
- Barnes**.....163
- Barrus calorimeter**.....76
- Barry County**.....194, 201
- Bates, T. T.**.....143, 157
- Battle Creek**.....26
- Bay No. 2 coal shaft**.....43, 45
- Bay City**.....12, 28, 37, 49, 70, 109, 116, 130, 133, 137, 170, 189
- Bay County**.....46, 49, 65, 110, 160, 166
- Bayport limestone**.....27, 29, 122, 160, 192, 194
- Bearinger Block well**.....181
- Bellevue limestone**.....205, 220
- Bellmore, W. Va. coal**.....78
- Benham, F. G.**.....91
- Bennington**.....200
- Berea shale**.....175
- Berea grit**.....29
- Berthier's formula**.....54, 80, 81
- Bicarbonated waters**.....101
- Big Muddy coal**.....97
- Big Rapids well**.....161
- Bingham Township**.....105
- Bituminous matter**.....16
- See also ANALYSES.
- Black Diamond Coal**.....71
- Black Jack**.....16
- Blackmar**.....177
- Black Pearl coal**.....45, 80, 189
- Black shales, Devonian**.....26, 27, 77, 105
- Blacksmith's coal**.....17
- Bliss, A. T.**.....176
- Blodgett, O. W.**.....37, 104, 178
- Blumfield**.....179
- Bog iron**.....101
- Boiler trial of coal**.....67, 68, 71, 72
- Boomer coal**.....72
- Borings, cost of**.....149
- Boyd's farm**.....219
- Boyle's mine, coal**.....98, 203
- Bradley, N. P.**.....133, 169, 170
- Bradley, F. F.**.....51, 91, 105, 107, 116
- Brewer Lumber Company**.....176
- Briar Hill coal**.....46
- Bridgeport Township**.....127
- Bristol, England**.....146
- British Thermal Units**.....53, 81, 89, 110, 111, 113, 117, plate II.
- Bromine**.....26
- Brookville coal**.....44, 46
- Brown farm**.....196
- Burns, A.**.....219
- Butler County, Pa., coal**.....17
- C.**
- Cadwell, H. R.**.....210
- Calamites**.....6, 44, 47
- Calcite**.....125
- Caledonia Township**.....197
- Calhoun County**.....218, 219
- Calories**.....53
- Calorimeter, Barrus**.....76
- Carpenter.....52, 78
- Parr, description of.....73, 75, 76, 82
- Thompson.....76
- Williams.....73, 87
- Tests by G. B. Wilcox.....78
- Campbell's washer**.....16
- Canada**.....28
- Candle coal**.....19

- Canfield, V. R. 71
 Cannel coal. 13, 17, 18, 19, 20,
 55, 91, 99, 105, 186
 Carbon, heating power of. 53, 85
 Carbon, Fixed. See ANALYSES.
 Carbonate of iron. (See KIDNEY
 ORE) 24, 188, 205, 219, 220
 Lime. (See LIMESTONE) ... 24
 Carboniferous 37
 See COAL MEASURES and
 EOCARBONIFEROUS.
 Cardiocarpon 44, 93
 Carlisle 204
 Carpenter, R. C. 52, 56, 78, 208
 Carpenter calorimeter. 76, 77, 108
 Carrollton 185
 Carterville 97
 Castner, Currant and Bullitt. 72
 Cass River 121
 Catlett, Chas. 123
 Cedar River 121
 Cedar Grove 71
 Central Coal and Mining Co. 42,
 45, 96, 110, 171
 Channel, gravel filled. 33, 48, 122,
 123, 129, 186
 Chapman Lake 158
 Chappell and Fordney Coal Co. 38,
 182, 184
 Chappell, W. T. 180, 205, 219
 Charcoal. 16, 17, 18, 22
 Charlevoix 20
 Charlotte 205
 Chelsea 22, 121
 Chelsea Compresso Peat Co. 22, 109
 Chester 29
 Chippewa River 162
 Chonctes Flemingi. 42
 Christie, W. W. 52
 Christopher 209
 Churn drills 131
 Clark, A. L. 161
 Clark, A. N. 51, 90, 94, 101, 114
 Clark Street well 181
 Clarksburg 17
 Clay 57, 89, 172
 See FIRE-CLAY.
 Clay seams 126
 Clearfield 97
 Cleat of Coal 15, 16
 Cleveland-Cliffs Company. 151, 154
 Cleveland market 155
 Clyde 160
 Coal 15, 38, 209
 Analyses. 17, 51, 54, 110 to 119
 (See ANALYSES.)
 Area of. 143
 Barnard, or "Uncle Henry" 180
 Beds of Kansas 42
 Bituminous 18
 " gas 17
 " cubical. 17
 "Block" 15, 18
 Bone. 19, 20, 22, 55, 93, 109, 117
 Boundaries of. 26
 Brookville 44
 Butt of. 15
 Comparative value of Sagi-
 naw and Hocking Valley
 coal 64, 67, 70
 Consumption of. 144, 145, 148
 Regulation of. 147
 Lower Peninsula 154
 Cost of. 138, 139, 141
 "Cubical" 15, 18, 19
 Development of. 129
 Erosion and disturbance of. 121
 Face of. 15
 Fibrous 16
 Freight rates. 138, 145
 Furnace 18
 Grand Ledge 45
 Heat, distribution of. 66
 Heating power of. 54, 65, 73
 Practical tests for. 66
 Heat saving 77
 Horizons 37, 45
 In acre 146
 Lands 153
 Value of. 139
 Labor value of. 137
 Lease 150, 156
 Lower 34
 Lykens 46
 Mercer 45
 Michigan 57, 66, 90
 Quantity of. 143 to 146
 Price of. 142, 147, 149
 Production of. 148
 Quality of 51
 Relation of drift to. 26
 Royalties, value of 149, 151
 Sebewaing 21, 30
 Seams, position of. 41

- Coal—Con.**
 Sharon 46
 Soft 18
 Specific weight 110, 146
 Splint 18
 Slaty 55
 Steam 18
 Tar 65
 Thickness of 144
Coal measures 30, 163, 175
 Lower 49
 Thickness of 31
 Upper 42, 49
 See also names of mines and
 mining towns, ANALYSES,
 and RECORDS.
Coat's Creek 121
Coffron, W. H. 104
Coke 18, 65, 108
 Briquette 21
 For iron manufacture 65
Coking 20
Colburn, L. C. 52, 73
Coldwater shales 175
Coleman 162
Combustible. (See ANALYSES.)
Compression 7
Conditions of workability of coal. 35
Conger, Mrs. Mary 201
Conglomerate 91, 202, 205
Connelsville coal 17
Continuity of coal fields 27, 29
Corbett, E. J. 71
Cordaites 44, 93
Correlation of coal 42 to 50
Corunna .24, 27, 31, 32, 36, 39, 40,
 41, 43, 45, 47, 49, 70, 71, 103,
 114, 121, 129, 133, 141, 142,
 196, 197
Coreyell, J. 164, 166
Coshocton County coal 17
Courier, Wm. 39
Cross-sections plate IX 25
Crow Island 38
Currie, Dougald 163
Cypress 8
- D.**
- Dalley, John** 71
Danger from unmapped mines 151
Daniel's farm 219
Davenport street well 181
Davis, C. A. 51, 104, 105, 174, 191
Denton, C. A. 174
Depth to bed rock 161
Des Moines series 50
Detroit 20
Devonian 175
Devonian black shales 26
 (See BLACK SHALES.)
Diamond drill 133, 169
Dickman 105
Dimondale 121
Discinisca(=Orbiculoidea) 43
Dixon, H. L. 65
Douglass, C. C. 3
Dow, H. H. 162
Downey House well 211
Drills, Churn 131
 Cost of 149
 Diamond 169
 Rotary 132
Duff Gas Producers 64
Dundee limestone 175
Durand 39, 40, 199
Dusch, Wm., coal on farm of 174
Dulong's formula .54, 81, 82, 83, 84,
 85, 86, 87, 88
- E.**
- Eastman farm, coal on** 181, 185
East Saginaw 32, 34, 38, 45, 124, 183
East Thetford 200
Eaton County 201
Eaton Rapids 121, 201, 202
Eddy and Sons, C. K., well of .38, 182
Edgerton, Edmond A. 66, 69
Edward's Lake 158
Elk 129
Elsie 197
Elva 194
Emerson coal shafts near Jackson 220
Engineering and Mining Journal 25
Englehardt 7
Eocarboniferous limestone 176,
 177, 185, 189, 191, 194, 196,
 201, 205, 207, 212, 220
 See also BAYPORT limestone.
Eschka's test for sulphur 60, 61, 101
Essexville, salt rock at 169
Etzold, J. A. 96, 133
Eureka Coal Co., Arenac Co. 105
Eureka Coal Co., Jackson Co. 220
Evart, prospects of coal at 161

- Exposure, effect of on coal**.....18, 52
Explorations, methods of.....130, 131
- F.**
- "Fake"**.....203
Faults and displacements...124, 126
Fe CO₂.....188, 205, 219, 220
Ferns.....6, 44, 47
Ferrie hydrate.....64
Figure 1. Cross-section of Michigan Basin.....25
Figure 2. After Keyes, shore line advances.....30
Figure 3. Section at Sebewaing shaft.....31
Figure 4. Woodville shaft....31, 33
Figure 5. Porter coal mine...48, 146, 220
Figure 6. Sulphur and iron in coal.....59, 100
Figure 7. Cross-section of cartridge for Parr calorimeter 74
Figure 8. Cross-section of Parr calorimeter.....75
Figure 9. Sketch map of Sebewaing coal region.....173
Fire clay.....24, 151
 Also in most of the records after p. 158.
Firth, Mr......160
Fisher, E. C., boiler test by.66, 67, 70
Fixed carbon.....17, 63
 (See the ANALYSES also.)
Flint River.....121
Flushing.....118, 200
Fold in strata.....182
Fordney, J. W......38, 45, 182, 184
Formation of coal.....7, 12, 13, 49
Fowler, W. F......198
Frankenlust Township.....122
Freeport Coal.....36
Fritsche, Dr. P......22, 52, 55, 60, 61
Fuel gas.....21
- G.**
- Gage farm**.....181
Garfield.....38, 176, 183, 189, 190
Gas.....63, 105, 107, 108
 See VOLATILE COMBUSTIBLE.
Gas coal.....18, 20, 94
Gas manufacture.....20
Gas tests.....64, 88
- H.**
- Haas**...52, 56, 63, 73, 82, 83, 84, 88, 89
Hale, R. S......52
Handy Bros, mine.....45, 106, 177
Hanna, M. A. Coal.....72
Hazelton Township.....198
Hardenberg and Sager.....174
Harper's Monthly.....143
Harrington House.....174
- Gelkie, A.**.....7
Gelnitz.....47
Genesee county.....200
Geological Survey, Role of.....135
Geological Society of America....3
George's Lake, well at.....158
Gerstacher farm, coal at.....165
German division of coal measures..47
Germain factory, salt well at.....176
Getchell, Dr......161
Girty, G. H., fauna determined by
 viii, 42, 43
Glacial deposits.....122, 129, 183
 See also records from p. 157 on
Gladwin county.....159
Glencoe.....168
Glen Mary Coal.....23
Goetz coal No. 1.....118
Goshen Hill Coal.....71
Golden, Colo......17
Gooch.....56
Goodell, E. G......200
Gordon, C. H......194
Grand Haven.....26
Grand Ledge..24, 39, 43, 44, 45, 46, 49, 57, 92, 113, 114, 121, 123, 130, 142, 194, 196, 203, 205
Grand Ledge Sewer Pipe Co....98
Grand River.....121, 203, 204
Grand Rapids...27, 103, 163, 172, 175, 194, 196
 Group.....197, 199, 201
 See also EOCARBONIFEROUS LIMESTONE.
Graphite.....17
Gratiot county.....174
Grayling.....143
Gregory.....160
Gresley, W. S......3, 126
Grove.....161
Gypsum, sulphate of lime.....16, 27

- Harz, Germany..... 22
 Heating power.....71 to 120
 Heavenrich, W. and C., borings of
 131, 185
 Helm Bros., analyses..... 104
 Henriett, Mr..... 180
 Herpel's farm.....177, 187
 Herrick, C. L..... 28
 Higgins, S. G...3, 105, 177, 183, 189, 193
 "Hills" in coal..... 31
 Hillsdale county..... 26
 Hilton, C. H. 51, 52, 55, 56 to 60, 81,
 90, 91, 92, 97, 99, 100, 102, 113
 History..... 1
 Hocking Valley coal...67, 70, 71,
 72, 78, 88, 104, 138
 Hodge, Chas..... 98
 Holcroft, John, Esq...3, 28, 32, 123,
 143, 166
 Holland.....22, 26
 Holliday, F. E..... 201
 Hollister Block, well at..... 211
 Holmendinger, John, coal at farm
 of..... 220
 Holmes, Chas.....103, 143
 Hope, Martin G..... 200
 Horrocks, Jas..... 194
 Horsebacks. (See BARS.)..... 128
 Houghton, Douglass..... 3
 Howell Condensed Milk Company 218
 Hubbard, coal near.....130, 164
 Hubbard, Bela..... 3
 Hubbardston..... 195
 Huron county.....3, 26, 122, 172
 Huronian slates, Upper..... 17
 Hydrogen'...62, 83 to 86, 110 to 112
 Hydrogen sulphide..... 63
 Hygroscopic moisture in coal...57,
 100, 108

 I.
 Ice sheet..... 122
 Illinois coal, relative age..... 42
 Imperial coal..... 183
 Indiana, coal of2, 49
 Industrial School well 209
 Ingham county, coal of 205
 Ionia.....121, 194, 195, 196
 Iosco county, coal not in 158
 Iowa.....2, 12, 32, 34, 42
 Iron...14, 20, 21, 58, 59, 81, 84, 85,
 86, 94, 99, 100, 101, 110, 113
 Iron, bog..... 101
 Iron, effect of in ash.....21, 85
 Iron ore..... 195
 Isabella county..... 161
 Island House (Mudge)..... 204
 Island Lake..... 26
 Ithaca.....34, 40

 J.
 Jackson...3, 12, 28, 29, 32, 36, 37,
 43, 46, 49, 106, 110, 114, 116,
 121, 126, 129, 130, 141, 146,
 160, 220
 Jackson cannell..... 114
 Jackson coal.....20, 64, 87, 105, 127
 Jackson County.....219, 220
 Jackson Gas Works..... 105
 Jackson Hill coal.....71, 78
 James Township.....45, 47, 183
 Jefferson Avenue wells, Lansing. 210
 Jenkins, C..... 160
 Jenkins, Irving.....98, 203
 Johnson, A. W..... 190
 Johnson, W. H..... 105

 K.
 Kaolinite..... 24
 Kaskaskia limestone.....13, 29
 See EOCARBONIFEROUS LIME-
 STONE.
 Kawkawlin..... 169
 Kedzie, Prof. F. S...51, 56, 80, 89,
 104, 105
 Kelley's Creek..... 72
 Kent county.....121, 194
 Kent, Wm.....52, 56, 83, 84, 87, 88
 Kentucky..... 42
 Kerr, C. V.....52, 80, 81, 82
 Keyes...2, 7, 12, 29, 31, 32, 35, 37,
 41, 50, 124, 125, 127, 143
 Keystone Tumbler Company.... 64
 Kidney ores..... 24
 See CARBONATE OF IRON.
 Kincaid, Tod.....24, 93, 103, 198
 Kinkad coal..... 97
 Kinderhook series..... 29
 King..... 209
 Kingston..... 194
 Kittaning coals.....35, 88
 Kniffin M. H.....105, 115, 196
 Knight, J. B..... 142

- Kochner farm**..... 181
Kochville..... 122
Koenig, Prof. G. A...... 65, 86
Kuntze, Dr. Otto. 7, 8, 9, 10, 11, 12, 14

L.
Lake County..... 158
Lamination of coal..... 16
L'Anse..... 17
Lansing..... 36, 138, 202, 203, 209, 211
Lansing Condensed Milk Co. well 210
Lansing Water-works tests. 57, 71, 72, 96, 210, 211
Lantz well..... 211
Larkin well..... 162
Lathbury and Spackman..... 109
Lathrop, Dr...... viii, 175
Lawton, C. D. 3, 39, 129, 141, 142, 160, 197
Lead, reduction of, determining heating power..... 82
Leases..... 152, 156
Lease of Cleveland-Cliffs Mining Company..... 154
Leasia wells..... 207
Lebanon Township..... 195
Lee Township..... 219
Lehigh coal..... 17
Lengsville..... 166
Leonard..... 49
Lepidodendron..... 6, 44, 45
Lepidophyllum cultriforme..... 44
Lesley, J. P...... 2
Lesquereux..... 6, 7, 10, 11, 37
Lignite..... 21
Liken Coal Company, J. C...... 172
Limerock..... 38
Limestone..... 24, 27, 40, 43, 46, 132, 160
 Arenaceous..... 176
 Bayport=Maxville..... 28
 Bituminous..... 34
 Dolomitic..... 175
 See also EOCARBONIFEROUS, and many of the well records after p. 158.
Limnic coal..... 10
Lincoln, L. J...... 195, 201, 207, 208, 210, 211, 218
Linders, A. W. H...... 104
Lingula mytiloides..... 20, 42, 98, 106
Lingula shale..... 23, 43, 46, 49, 96, 99, 160
Livingston county..... 218
Logan series..... 27, 28
Long wall system of mining..... 146
Loranger, U. R...... 109, 157, 171
Lord, N. W...... 52, 56, 63, 73, 82, 83, 84, 88, 89
Lower Clarion measures..... 46
Lower Kanawha formation..... 44
Lower Verne..... 12, 43, 45, 110
 See VERNE COALS.
Lowery Coal Company..... 72
Ludington..... 26
Luhrig process of coal washing... 16
Lycopodium..... 6, 19
Lykens Valley coal..... 17, 41, 46

M.
Mackenzie, analysis by..... 105
Mahler calorimeter..... 73, 108
 See CALORIMETER.
Mammoth coal seam..... 23
Mansfield, R. J...... 99
Maple Hill..... 174
Maple Rapids..... 197
Marcasite..... 58
 See SULPHUR and PYRITE.
Mariopteris cf. inflata..... 93
Marshall sandstone..... 11, 12, 27, 30, 37, 49, 163, 195
 Upper..... 176
 See NAPOLEON.
Mason, wells at..... 208, 212, 213, 214, 215, 216
Mason, Z. T...... 159, 162, 166
Mason, F. H...... 176
Massillon coal, O...... 17, 24, 41, 46, 49, 71, 78
Massillon coal, Bay Co...... 118
Maxville limestone..... 27, 28, 41
McCarty, T...... 191
McDonald, D. A...... 180, 181, 185
McDowell, J...... 218
McKinnon, A. C...... 176
McMillan, A. M...... 185
Michigan series..... 40, 197
Michigan Coal Co...... 70, 72
 See BLACK PEARL and ST. CHARLES.
Michigan Coal and Mining Co...... 23, 42, 45, 71, 72, 96, 113, 116, 118, 133, 171, 189
Michigan Miner..... 1, 77, 97, 149, 157

- Michigan Standard Mine...43, 91, 95
See SEBEWAING.
Midland...26, 30, 34, 36, 41, 49, 122,
161, 162, 164, 166
Miller, Peter... 171
Millett... 39, 202
Millington... 194
"Millstone" grit... 41
See POTTSVILLE.
Milton Coal Company... 71, 72
Mineral Spring Hotel (Grand
Ledge)... 39
Mines and Minerals...36, 123, 133,
143, 153
Minie, Mr... 202
Mingo coal... 71
Missaukee county... 157
Missouri, seams of... 142
See also KEYES AND WINSLOW.
Moisture... 65, 100, 108
Determination of... 56, 99, 100
See also ANALYSES.
Monitor Coal Co... 36, 43, 45, 46,
106, 109, 118, 120, 166, 171
Montana Coal and Coke Company... 72
Montana lump... 78
Montcalm county... 130, 172
Moraine, above Jackson City... 94
Mount Olive coal... 97, 112
Mount Pleasant... 161, 162
Munger... 37, 104, 169, 178
Muskegon... 26, 130, 159, 161
- N.
- Napoleon sandstone... 26, 30, 32, 34,
38, 40, 103, 172, 175, 177, 189, 199
Nashville water-works... 201
National Mining Company... 219
Nebraska City beds... 42
Neuropteris... 44
Newaygo county... 161
New Baltimore... 27
Newberry... 46
New Haven... 198
New Hope Coal Mining Co... 32, 93,
106, 110, 114, 116, 219
New River coal... 41, 71, 78
Nicolls, W. J... 3, 34, 139, 140, 149
Nims, C. S... 161
North American Chemical Co... 37
Northern Coal and Transporta-
tion Co... 80
- North Star... 174
Nucula ventricosa... 42
- O.
- O'Donnell Spencer Co. well... 124 185
Ogemaw County... 157
Ohio Central Fuel Co... 71
Ohio... 2, 17, 32, 35, 36, 47, 122, 141,
143, 150
Correlation with... 24, 26, 27,
28, 29
See ORTON and NEWBERRY.
Oliver farm... 179
Olsen, N... 174
Omer... 121, 160
Ontario... 21
Orbiculoidea... viii, 42
See also DISCINISCA.
Orthoceras... viii, 42
Orton, E... 2, 18, 29, 32, 34, 36, 140,
141, 143, 146, 150
Osage district... 141
Osceola County... 159
Oscoda wells... 158
Overproduction... 152
Ownership, State... 147
Owosso... 39, 40, 46, 49, 110, 197, 198
Owosso Coal and Mining Co... 24,
44, 45, 92, 113, 197
Ozark uplift... 29
- P.
- Paines... 122, 186, 190
Palmerton Woodenware Factory,
183, 186
Parma... 13, 26, 27, 37, 38, 40, 41, 49,
103, 143, 163, 169, 175, 176,
195, 196, 199, 201, 207
Parr Calorimeter... 73 to 76, 82, 92, 109
Patterson, D. A... 142
Paul, Goff... 171
Peat... 6, 21, 22, 34
Peat analyses... 109, 119
Pelagochthonous coal... 9
Pennock, J. D... 64, 66, 107, 108
Pennsylvania, coal in... 27, 46
See NICOLLS and STEVENSON.
Pennsylvania Geological Survey,
2, 10
Pere Marquette No. 1... 32, 47, 77,
89, 90, 108, 110, 113, 114, 116,
127, 151, 184, 185

- Pere Marquette No. 2.** 38, 78, 114, 182, 183
Peter, J. B. 180
Peyton's cannell. 17
Phillips, H. J. 51, 56, 57
Phillips, J. T. 91
Phillips, T. C. 105
Phillips, C. M. 205
Phosphorus. 21, 110
Platt's well. 211
Pierce, Henry. 195
Pinches in coal. 33
Pinconning. 98, 113, 130, 160, 168
Pittsburg coals. 64, 71, 72, 88, 97, 112
Pittsburg Co., Amelith shaft. 43, 171
Pleistocene. 103, 163, 175 176
Pleurophorus oblongus. 42
Pocahontas coal. 18, 41, 71, 77, 78, 97, 112
Poole and Emerson. 220
Porter Coal Mine. 48, 123, 124, 146, 220
Port Huron. 20
Portsmouth. 122
Portland Cement Manufacture. 58, 120
Potter, H. C. viii, 37, 176
Pottsville formation. 12, 24, 41, 43, 45, 46, 49, 50, 103
Prairie farm. 38, 186, 187, 190
Pratt mine. 196, 203
Pratt, Geo. H. 211
Pray, T. T. 56, 73, 108
Pre-Allegheny age of coal. 44
Price of iron ore. 154
Productus. 23, 42, 49
Promoter, use of. 5, 135, 136, 137
Pseudopecopteris. 44
Pumpelly, R. 136, 138
Pulverization. 18
Putnam Hill coal. 46
Pyrite. 55, 58, 59, 60, 81, 89, 94, 100, 132
 See also SULPHUR.
- Q.**
- Quakertown coal.** 24
Quicklime to purify gas. 64
Quicksand, how to meet. 131
- R.**
- Randall, Robert M.** 80
Beardon's well. 162
Reed and Bradley. 90, 105, 106, 107, 116
Rhodes, coal near. 130
- Rider.** 32, 34
 Upper. 34, 46, 203, 204
 Middle. 34, 46, 107, 169, 186
 Lower. 34, 169
Ries, H. 95, 103
R de River. 4, 43, 77, 105, 113, 121, 130, 160
Rises in coal. 31
Riverside mine. 38, 45, 71, 78, 182
Robert Gage. 219
 Coal Co. 45, 109, 117, 188
Robson, J. Hon. 209
Rogers, H. D. 143
Rominger, Carl. 3, 4, 14, 31, 34, 39, 43, 45, 99, 105, 143, 160, 169, 199, 202, 204, 205, 219
Roof of coal. 23, 90
 See also various records from p. 90 on.
- S.**
- Saarbruck coal.** 66
Saginaw. 26, 28, 30, 36, 37, 38, 45, 90, 91, 108, 114, 121, 135, 175 to 191
Saginaw Bay. 13
Saginaw Bay Coal Company. 104
Saginaw Board of Trade. 3, 183
Saginaw Clay Manufacturing Co. 104
Saginaw Coal Co. 45, 71, 78, 80, 104, 107
Saginaw county. 49, 121, 122, 143, 175
Saginaw Evening News. 4, 105
Saginaw seam. 34, 45, 51, 64, 67, 70, 71, 77, 78, 87, 88, 92, 96, 104, 106, 107, 108, 110, 117, 120, 183, 184, 186, 187, 189, 190, 193, 205, 206, 219, 220
Saginaw Valley. 138, 142
St. Charles. 11, 12, 31, 38, 45, 46, 70, 72, 77, 78, 106, 109, 110, 116, 117, 136, 176, 183, 186, 188, 189, 190
 See also ROBERT GAGE COAL CO., BLACK PEARL COAL, J. H. SOMERS SHAFT, No. 1.
- St. Charles Coal Co.** 31, 45, 117, 188
St. Johns. 34, 36, 40, 195, 196, 197
St. Louis. 26, 34, 40, 41

- St. Louis magnetic well** 174
Salt 2, 14, 26, 38, 64
Salt River 143
Salt Rock, upper and lower 38
 See PARMA, NAPOLEON AND MARSHALL.
Salzburg 65
Sampling 54
Sandstone 46
 Bar 34, 47, 182
 Conoquenessing 46
 Homewood 45, 46
 Massillon 46
 Napoleon or Upper Marshall 26
 See NAPOLEON.
 Parma 26, 27, 40, 49, 143, 169, 193, 196, 199, 207
 See PARMA.
 Quarry 211
 Red 40
 See all records from p. 157 on.
Sanford 164
Sanilac county 26, 27
Saranac 194
Sawdust in purifying gas 64
Schaefer, C. B. 3
 See also MICHIGAN MINER.
Schaefer, J. V. 16
Schaltberger, G. 181, 185
Schickle, Dr. 200
Schuykill coal 17
Scott, A. J. 192
Scott, W. B. 14
Screens 140
Sebewaing 11, 12, 20, 22, 24, 28, 30, 31, 34, 36, 45, 46, 47, 49, 102, 110, 113, 114, 116, 125, 130, 140, 151, 172, 173, 194
Sebewaing Coal Co. 32, 95, 103, 125, 129
 See also MICHIGAN STANDARD COAL CO.
Sewanie zone 44, 46
Semi-anthracite coal 17
Semi-bituminous coal 17
Shadbolt, O. A. 205, 207, 219
Shadoin's well 209
Shafts 134
Shale, black 19, 20, 23, 34, 175
 See DEVONIAN and LINGULA SHALE, also many records after p. 158.
Sharon 24, 35, 41, 44, 46
 Conglomerate 46
 Group 45
Shattuckville 186
Shearer Bros 169
Shepherd, W. H. 159
Sheridan Township 219
Sherwood, George F. 105
Shiawassee river and county 121, 197
 See OWOSSO and CORUNNA.
Shipman, O. W. 71, 72
Sigillaria 6, 45, 47
Silver Mather Company 72
Six Mile Creek 39, 198, 199
Slack 108, 117, 126, 140
 See BONE COAL.
Slate 22, 24
Slopes (inclines) 129
Slosson, E. C. 52, 73
Smeltzer, J. 157
Smith, W. O. 202
Smith's crossing 163
Soleniscus 42
Sollas, W. J. 6
Solvay process 64, 107
Somers, J. H. Coal Co. 31, 45, 70, 72, 91, 108, 110, 113, 189, 205
"Soot" veins 126
South Saginaw 122, 184
South Saginaw well 175, 176
South Side coal 71
Sovereign, E. C. 105
Spar seams 125, 126
Speidel, E. 102
Sperr, Prof. 47, 146
Sphagnum 8
Sphenophyllum cuneifolium 44, 203
Splitting of coal beds 23, 37
Spores 6, 13, 19
Standard mine 24, 43, 47, 92, 127, 186
 Analyses No. A2..90, 106, 110, 113, 116
 Fossils 44, 45
Standish 4, 130, 160
Star mine 152
Steam making, use of coal 20
 See HEATING POWER.
Sterling 160
Stevenson, J. J. 2, 23, 37, 124, 127
Stigmaria 6, 11, 14, 43, 44, 93
Stimson's, J. 185
Strope, Elmer E. 208

Sudbury district	145	Tloga county coal	17
Sulphates	14	Tionesta	46
Sulphides	20	Tittabawassee	143, 193
Iron	14, 15, 64, 151	T. 1 N., R. 2 W.	218
Zinc	16, 24, 93, 203	T. 1 N., R. 3 W.	202
See PYRITE and SULPHUR.		T. 2 N., R. 1 W. Sec. 3.	212, 215
Sulphur	14, 16, 18, 57, 58, 59, 60,	Sec. 9.	216
62, 81, 85, 86, 87, 94, 99, 100,		Sec. 14.	216
103, 107, 120, 125, 126		Sec. 20.	217
Determination of.	59	Sec. 22.	217
In ash.	21, 60	Sec. 27.	217
See also the ANALYSES.		T. 2 N., R. 7 W. Sec. 6.	201
"Swamp"	31	T. 2 N., R. 2 and 4 E.	218
T.		T. 2 N., R. 2 W. Sec. 23.	218
Taber, Frank A.	98	T. 2 N., R. 6 W. Sec. 24.	204
Table, comparative analyses	17	T. 2 S., R. 2 W. Sec. 24.	106, 219
A—Analyses by H. J. Wil-		T. 2 S., R. 4 W. Secs. 13 and 24. ..	219
liams	110	T. 3 N., R. 3 E. Sec. 25.	202
B—Analyses of dry coal by		T. 3 S., R. 1 W. Secs. 12 and 13. ..	220
H. J. Williams	111	T. 4 N., R. 1 E. Sec. 28.	205
C—Analyses for comparison		T. 4 N., R. 2 E.	207
by H. J. Williams	97, 112	T. 4 N., R. 1 W. Sec. 18.	208
D—Analyses by C. H. Hilton,		T. 4 N., R. 1 W. Sec. 33.	207
E—Analyses by A. N. Clark	114	T. 4 N., R. 2 W. Sec. 10.	98
F—Proximate analyses	114	Sec. 15.	209
G—Partial and proximate		Sec. 18.	208
analyses	115	T. 4 N., R. 3 W. Sec. 35.	39, 202
H—Analyses by Bradley and		T. 4 N., R. 4 W. Sec. 11.	204
Reed	116	T. 5 N., R. 1 W. Sec. 24.	196
I—Recent analyses (mainly		T. 5 N., R. 4 W. Sec. 26.	196
tested calorimetrically)...	117	T. 7 N., R. 2 E. Sec. 5.	39
J—Supplementary analyses.	118	T. 7 N., R. 3 E. Sec. 13.	103
K—Peat analyses by W. H.		T. 7 and 8 N. R., 4 E.	198
Allen	119	T. 7 N., R. 6 E. Sec. 26.	194
Tamarack swamp	8	T. 7 N., R. 7 E. Sec. 7.	201
Tar	21, 63, 107, 108	T. 7 N., R. 2 W. Sec. 9.	196
Tawas	26	Sec. 13.	105
Teed, W. H.	160	T. 8 N., R. 5 E. Secs. 15, 22.	104
Tests of coke	65	T. 8 N., R. 5 E. Secs. 4, 15, 22, 26. ..	200
Tests of boilers	68	T. 8 N., R. 4 W.	195
Test "Alternate method"	70	T. 10 N., R. 3 E. Secs. 15 and 16. ..	188
"Standard method"	70	See ST. CHARLES.	
Test by Mr. Edgerton.	69, 71, 72	T. 10 N., R. 4 E. Sec. 12.	187
Tests by Parr Calorimeter	92	Secs. 16, 23.	186
Test pits	131	T. 10 N., R. 7 and 8 E.	191
Testing	53	T. 10 N., R. 5 W. Sec. 7.	177
Thornapple	201, 204	T. 11 N., R. 3 E. Secs. 15, 24. ..	186, 190
Thompson Calorimeter	76	Secs. 25 and 26. ..	186
Thunder Bay	20	T. 11 N., R. 4 E. Sec. 7.	182, 186
		T. 11 N., R. 10 W. Sec. 11.	174
		T. 12 N., R. 1 E. Sec. 24, 26.	190

- T. 12 N., R. 4 E.** Secs. 21, 22, 27,
 28, 33 and 34... 183
 Sec. 24..... 176
 Sec. 34..... 186
 Sec. 35 175
T. 12 N., R. 5 E. Sec. 9 181
 Secs. 21, 30..... 185
 Sec. 29..... 176, 185
 Sec. 31 107, 184
 Sec. 32..... 184
T. 12 N., R. 6 E. Sec. 18 180
T. 12 N., R. 7 E. Sec. 30 193
T. 13 N., R. 9 E. Sec. 4 192
T. 14 N., R. 1, 2, and 8 E. 163
T. 14 N., R. 5 E. Secs. 3, 29, 33..... 181
T. 14 N., R. 9 E. Sec. 4, 18 192
T. 14 N., R. 8 W. Sec. 22 162
 Sec. 34..... 174
T. 14 N., R. 5 W. Sec. 28..... 162
T. 15 N., R. 2 E. Sec. 24 and 25. 164, 165
 Sec. 24..... 164
T. 15 N., R. 9 E. 173
 Sec. 18..... 172
T. 15 N., R. 1 W. Sec. 4 164
 Sec. 27..... 164
T. 17 N., R. 8 E. Sec. 10 ... 99, 160,
 166, 167
 Secs. 28, 34..... 167
T. 17 N., R. 2 W. Sec. 25 159
T. 17 N., R. 4 W. Sec. 16 159
T. 19 N., R. 4 E. Sec. 3 99, 160
T. 19 N., R. 5 E. Sec. 15 160
T. 19 N., R. 2 W. Sec. 3 159
T. 20 N., R. 6 E. 160
Thrash, Moses..... 169
Travis, B. E...... 92
Traverse formation..... 175
Trepostira sphaerulata..... 42
Troughs, elongate 47, 48
Trumbull Mining Company.. 106, 219
Turner 160
Tuscola..... 121, 122, 177, 191, 193
**Twentieth Century Portland Ce-
 ment Company** 92

U.

Ultimate analyses..... 61
Unconformity 27, 176
Undulations..... 31, 32, 33
Unionville 122, 191, 194
Units, British Thermal.. 53, 54, 63,
 76, 78 to 89, 110 to 113, 117
United States Geological Survey.
 Water Supply and Irrigation,
 Paper No. 30..... 4, 26, 42
Upper Marshall..... 26, 30, 175
 See NAPOLEON.
Upper Logan of Ohio..... 26
Upper Pottsville 43, 46
Uses of coal..... 20
 Of peat..... 21
Utricularia 11

V.

Vance, W. H. and Company..... 72
Van Osdall's farm..... 202
"Valleys"..... 31
Valley Coal Mining Company.. 43,
 45, 65, 106, 116, 171
Vassar 191
Venice Township..... 198
Verne coals... 20, 38, 43, 45, 46, 49,
 51, 65, 87, 88, 106, 109, 110,
 113, 163, 166, 171, 179, 183,
 184, 187, 188, 193, 196, 205,
 212, 219
Verne, Upper.. 34, 43, 45, 46, 70, 93,
 96, 98, 106, 110, 120, 179, 186,
 203, 204, 206, 207, 220
 Lower.. 34, 43, 45, 46, 70, 77,
 87, 92, 93, 95, 96, 98, 103,
 106, 107, 110, 113, 120, 127,
 179, 180, 186, 187, 198, 203,
 204, 206
Verne mine.. 12, 24, 42, 45, 95, 105,
 186, 187
Virden strike 140
Vitriol 16
Volatile combustible..... 20, 63
 See ANALYSES.

W.

"Wants" in coal..... 123
Wages 140, 141
Waldo farm 165
Ward, F. C...... 28
Ward, W. F...... 197
Watson well..... 209
Wayne County 27
Weldman 162
Well, Prof...... 51, 68
Wells, cost of..... 132
Well records, importance of..... 134
Wells & Clear..... 71

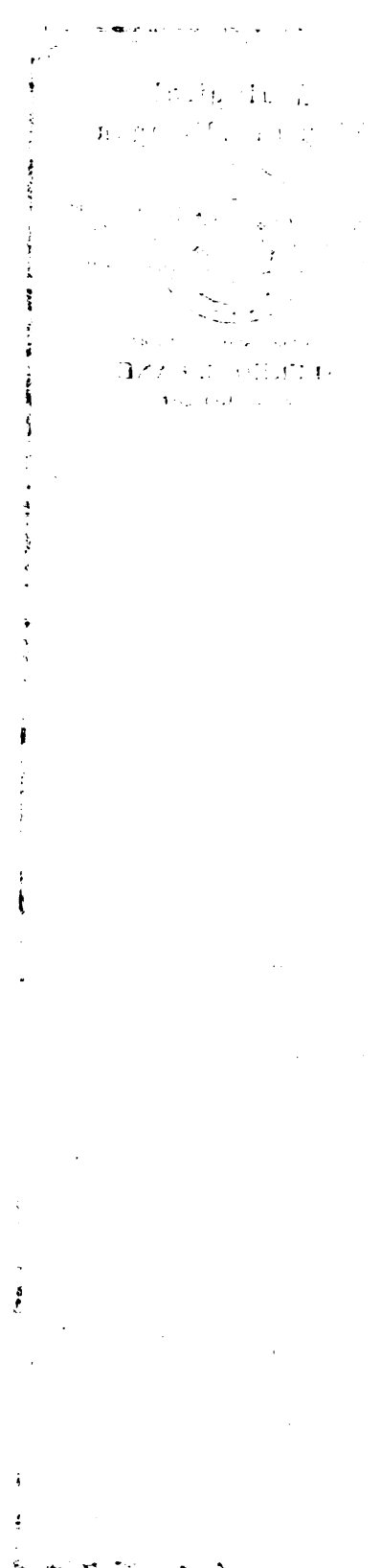
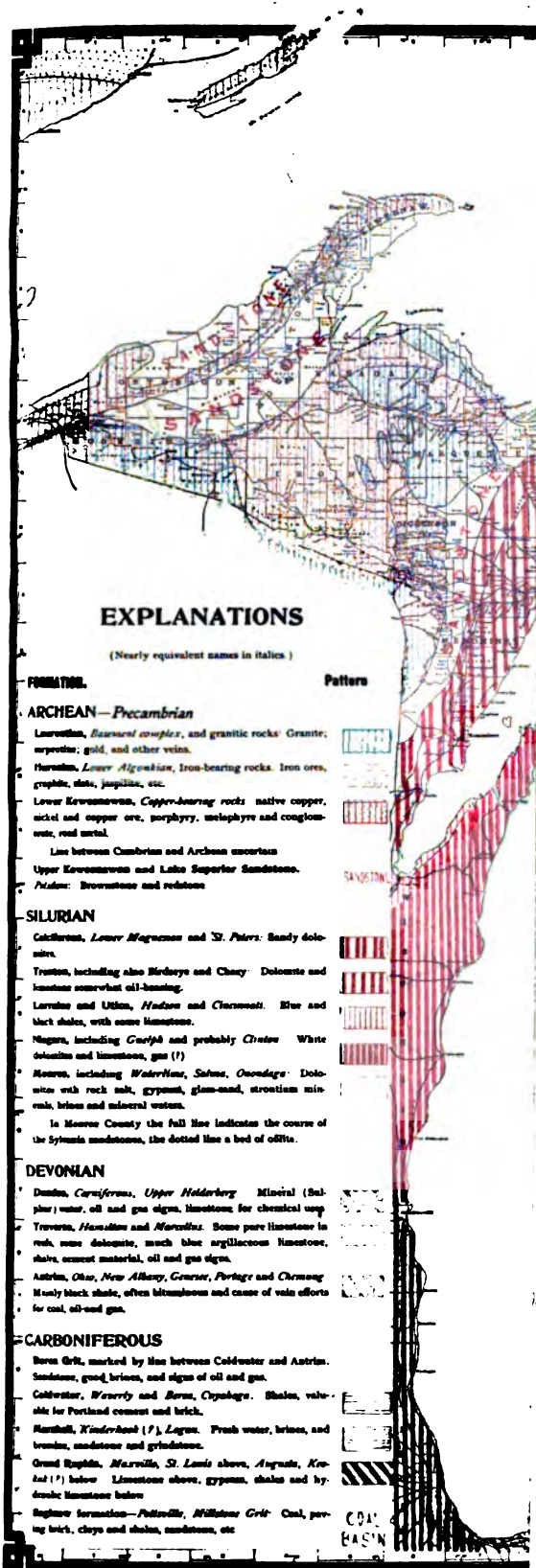
- Wellston coal**.....36, 71, 72
Wenona mine..20, 23, 42, 43, 45, 65,
 116, 177
West Bay City.....78, 116
Westhaven Township.....198
West Saginaw.....49
 See PERE MARQUETTE No. 2.
White, David....3, 6, 12, 36, 42, 43,
 45, 46, 49, 91, 204
White, I. C......24
Whitney, J. H......190
Wigant and King.....209
Wiggins farm.....181
Willcox, Geo. B...20, 51, 52, 66, 77,
 78, 94, 97, 101
Wilkinson, B. F......98, 203
Williams, H. J....18, 51, 52, 55, 56,
 60, 65, 73, 83, 87, 88, 89, 91,
 96, 97, 99, 100, 108, 109, 110,
 111, 112
Williamston..36, 43, 45, 46, 49, 70,
 121, 129, 202, 205, 212
Winchell, A....3, 21, 39, 40, 41, 64,
 104, 130, 143, 159, 174, 199,
 202, 209
Winslow, A......2, 10, 29, 35, 146
With, Mr......177, 193
Wolverine Coal Co....45, 130, 163, 171
Woodville mine..31, 33, 47, 106,
 122, 139, 219
 Sandstone.....40, 41, 175, 195
Woodward, I. C......78, 79
Wright, F......161
Wright and Lane.....3
Wuth and Stafford.....97, 104
Wylie Bros......176
Wyoming coal bulletin.....73

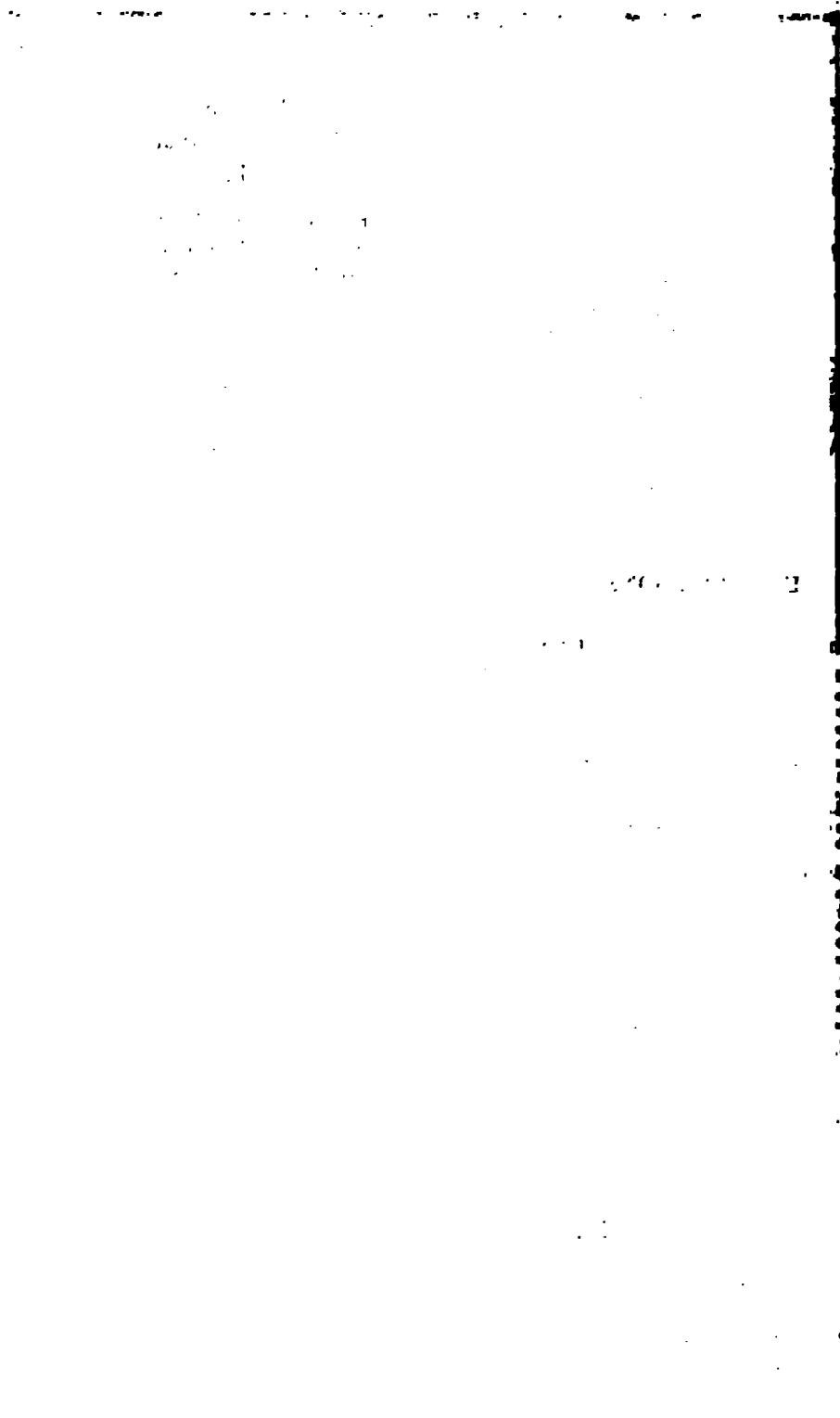
Y.

- Yeomans, M. W.**.....195
Yorkville.....97
Youmans, Henry M......177

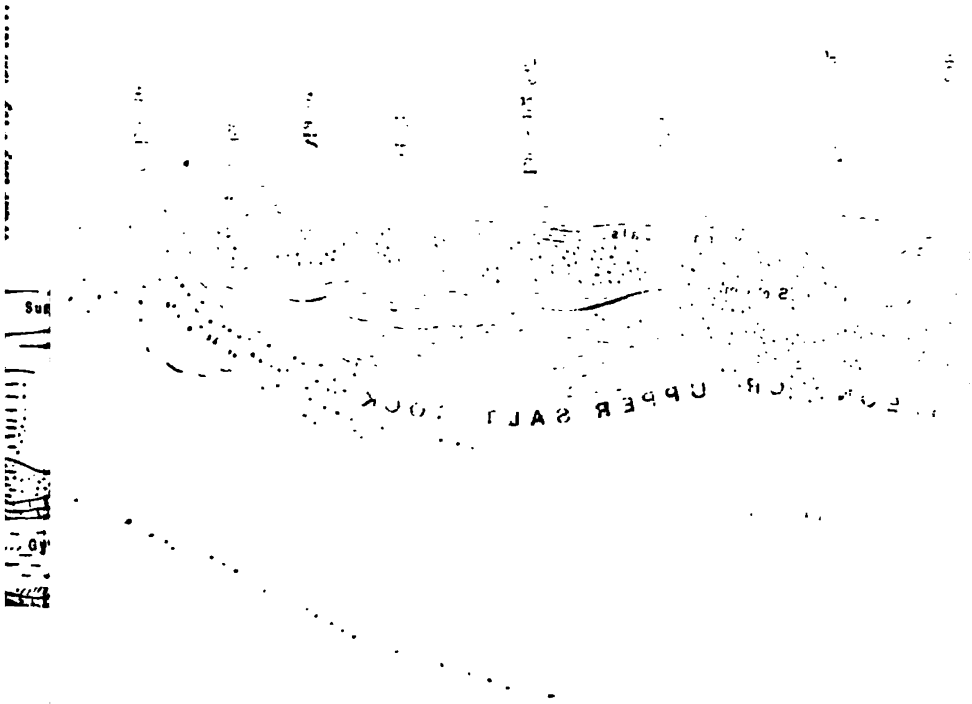
Z.

- Zagelmeyer, A. and F.**.....193
Zilwaukee.....122
Zinc nodules.....16, 24, 93, 203





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Long Line of Michigan Coalfield and Jackson Bay

Section of Coal Basin

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GEOLOGICAL SURVEY OF MICHIGAN

ALFRED C. LANE, STATE GEOLOGIST

VOL. VIII

PART III

MARL (BOG LIME)

AND ITS APPLICATION TO THE MANUFACTURE OF

PORTLAND CEMENT

BY

DAVID J. HALE

AND OTHERS

ACCOMPANIED BY TWENTY-THREE PLATES

AND

FORTY-THREE FIGURES

PUBLISHED BY AUTHORITY OF THE LAWS OF
MICHIGAN

UNDER THE DIRECTION OF
THE BOARD OF GEOLOGICAL SURVEY

LANSING

ROBERT SMITH PRINTING CO., STATE PRINTERS AND BINDERS

1903

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OFFICE OF THE STATE GEOLOGICAL SURVEY,
LANSING MICH., March 31, 1903.

To the Honorable, the Board of Geological Survey of Michigan:

HON. A. T. BLISS, *Governor and President of the Board.*

HON. L. L. WRIGHT, *President of the Board of Education.*

HON. DELOS FALL, *Superintendent of Public Instruction
and Secretary of the Board.*

GENTLEMEN—Herewith I transmit as Part III, the concluding part, of Vol. VIII, a report containing the results of examination of the raw materials of the Portland Cement industry, more particularly the beds commonly known as marl, but more properly known as bog-lime, for the more nearly pure calcium carbonate a bed is the more valuable it is.

My original plan was for a brief report something upon the order of that by H. Ries in Part I of this volume, arrangements for which were made about the same time, to be prepared wholly by Mr. Hale. But the subject grew upon him, and he obtained the promise of co-operation from Messrs. Lathbury and Spackman and R. L. Humphrey, whom we have to thank for their valuable papers.

I had also expressed to C. A. Davis my feeling that, for reasons which I have elsewhere given, none of the theories then current were competent to account for the origin of these very extensive and pure deposits of calcium carbonate. He suggested the agency of the algæ, and at my request worked the matter out, with the results herein incorporated, and I believe his contribution is a most valuable addition to science. In the meantime, facts of one sort and another kept accumulating, and so the present report was built up. I trust that its lack of unity may be atoned for by its value. If it trespasses rather far into the field of manufacturing for the economic geologist, I can only say that Mr. Hale thought that this would be useful, and that some description of the methods of manufacture were needed to understand those properties of the raw material which were most valuable.

This volume is already too large, or I should have been tempted to

add to the treatment of the three materials for cement considered herein, clay, coal and bog-lime, a fourth part on limestone. The State contains much limestone suited for the manufacture of Portland cement, and the question between it and bog-lime is a business one, whether it is cheaper to grind up the limestone or evaporate the water out of the marl. The output of a plant will ordinarily be increased by using ground limestone.

Nothing in science is final, and this report is not the last word on the subject. Prof. E. D. Campbell of the University at Ann Arbor is even now at work on a very important series of papers, affecting, however, more especially the theory of manufacture.

With great respect I am your obedient servant.

ALFRED C. LANE,
State Geologist.

TABLE OF CONTENTS.

CHAPTER I.

INTRODUCTION.

CHAPTER II.

USES OF MARL.

	Page
Sec. 1. Quicklime.....	3
2. Fertilizer.....	3
3. Minor uses.....	4

CHAPTER III.

THE USE OF MARL FOR CEMENT MANUFACTURE.

1. Description	5
2. General distribution	9
3. Prospecting tools.....	9
Method of operating.....	12
4. Location of marl.....	13
5. The distribution of marl in a single bed.....	16
6. Surroundings of marl.....	23
(a) Shore wash.....	4
(b) Streams	25
(c) Surface.....	25
(d) Silt under water.....	26
(e) Lining of marsh growth or decayed plant life.....	27
(f) Organic matter permeating deposits.....	27
(A) Organic matter of the marl deposit	27
(B) Organic matter of drainage.....	27
(g) Materials underlying marl.....	28
(h) Materials overlying marl.....	29
7. Method of prospecting a given area.....	29
8. Commercial importance of composition.....	30
(1) Appearance	31
(2) Composition	32
(3) Interpretation.....	34
Calcium carbonate.....	34
Magnesium carbonate.....	35
Ferric oxide and alumina.....	35
Insoluble and soluble silica	36
Soluble silica.....	36
Organic matter.....	37
Sulphuric and phosphoric acids, chlorine, etc.....	37
9. Location and size of bed.....	38

CHAPTER IV.

THEORIES OF ORIGIN OF BOG LIME OR MARL.

1. Introduction—the various theories.....	41
(1) Shell theory	41
(2) Sedimentary theory.....	42
(3) Chemical theory	42

Introduction—Continued:		Page
Sec. 2.	Shells	43
3.	Sedimentary theory	44
4.	Chemical theory	44
5.	Indications by circumstances of occurrence	47

CHAPTER V.

A CONTRIBUTION TO THE NATURAL HISTORY OF MARL.

BY C. A. DAVIS.

1.	Historical introduction.....	65
2.	Ultimate sources.....	66
3.	Alternative methods of deposition.....	66
4.	Cause of deposition upon aquatic plants.....	69
5.	Relative importance of Chara (Stonewort).....	70
	Analytical tests.....	71
	References in literature.....	77
	Sources of thick crust.....	79
6.	Marl beds without Chara.....	81
7.	Association of marl and peat.....	82
8.	Turbidity due to marl.....	83
9.	Conclusions.....	86
10.	Method of concentration by Chara.....	87
11.	Blue-green algae and their work.....	90
12.	Littlefield Lake, Isabella county.....	92
	APPENDIX, on the shells of marls BY BRYANT WALKER.....	97
	Notes	98
	Localities.....	99

CHAPTER VI.

RECORD OF FIELD WORK.

1.	Lansing—Summer, 1899.....	103
	White Pigeon.....	103
	Bronson, Quincy, Coldwater.....	104
	Jonesville.....	106
	Kalamazoo.....	106
2.	Cloverdale.....	107
	Cloverdale Region—Summary.....	128
3.	Pierson Lakes.....	131
4.	Lime Lake and vicinity	133
	Lime Lake.....	134
	Twin Lakes.....	134
5.	Fremont district.....	135
6.	Muskegon district.....	137
7.	Benzie county.....	137
8.	Harrietta.....	138
9.	Escanaba.....	138
10.	Munising.....	139
11.	Wetmore.....	139
12.	Manistique.....	140
13.	Corinne.....	140
14.	Grand Traverse Region.....	141
15.	Central Lake.....	142
16.	East Jordan and vicinity.....	148
17.	Manistee Junction.....	150
18.	Rice Lake.....	151
19.	St. Joseph River and tributaries.....	154
20.	Onkama.....	154

CONTENTS.

vii

CHAPTER VII.

MANUFACTURE OF PORTLAND CEMENT FROM MARL.

	Page
SEC. 1. Introduction.....	153
2. Definition of terms	158
3. Historical.....	159
4. Materials for cement.....	160
5. Kiln process of cement manufacture.....	162
6. The rotary process.....	163
7. Preliminaries	165
1. Digging.....	165
2. Draining.....	166
3. Dredging.....	166
8. Estimates on raw material	167
9. Requisites for marl deposit.....	169
Surfacing.....	169
Necessary composition.....	169
Depth.....	169
Sulphuric acid.....	170
Magnesia	170
Grain.....	170
10. Clay.....	170
11. Admixture of raw materials.....	171
12. Mixing and raw grinding.....	173
13. Burning	174
14. Clinker grinding.....	179
15. Motive power	184
16. Storage and packing.....	185
17. Specifications for cement.....	186
18. Buildings.....	188
19. Review.....	189

APPENDIX TO CHAPTER VIII.

THE DEVELOPMENT OF MARL AND CLAY PROPERTIES FOR THE MANUFACTURE OF PORTLAND CEMENT.

BY E. B. LATHBURY.

CHAPTER VIII.

NOTES ON THE ORIGIN OF MICHIGAN BOG LIMES.

BY A. C. LANE.

1. Introduction.....	199
2. Origin of bog lime, chemical considerations.....	199
Abstract of Treadwell and Reuter's article	201
1. Calcium bicarbonate.....	206
2. Magnesium bicarbonate.....	213
3. Calcium bicarbonate in solution with NaCl	213
4. Sodium bicarbonate.....	215
3. Microscopic investigations	218
(a) Microscopic precipitate by loss of CO ₂ and heating.....	218
(b) Precipitate by evaporation.....	220
(c) Chara fragments.....	220
(d) Blue green algae	221
(e) Shell structure	221
(f) Limestone flour.....	222
4. Conclusions.....	223

CHAPTER IX.

LIST OF LOCALITIES AND MILLS.

COMPILED BY A. C. LANE.

	Page
Sec. 1. Introduction.....	224
Alpena Portland Cement Co.	224
Omega Portland Cement Co.	227
Peninsular Portland Cement Co.	233
Peerless Portland Cement Co.	237
Bronson Portland Cement Co.	239
Newaygo Portland Cement Co. (Gibraltar Brand).....	240
Elk Rapids Portland Cement Co.	244
Wolverine Portland Cement Co.	246
Michigan Alkali Co., Wyandotte (J. B. Ford).....	248
Hecla Cement and Coal Co.	251
George Lake.....	252
Edwards Lake.....	253
Chapman Lake.....	253
Plummer Lake.....	254
Crapo Lake.....	254
Mills Lake.....	255
The Great Northern Portland Cement Co.	258
Detroit Portland Cement Co.	270
Egyptian Portland Cement Co.	272
Twentieth Century Portland Cement Co.	281
Zenith Portland Cement Co.	282
Standard Portland Cement Co.	288
Wayne Portland Cement Co.	291
Pyramid Portland Cement Co.	291
German Portland Cement Co.	291
Three Rivers Cement Co.	292
Farwell Portland Cement Co.	292
Clare Portland Cement Co.	293
Watervale Portland Cement Co.	297
Lupton Portland Cement Co.	297
Standiford Portland Cement Co.	301
Bellaire Portland Cement Co.	306
West German Portland Cement Co.	306
Locations reported by Douglass Houghton Survey.....	306
Marl.....	309
Local details of Marl, Jackson County.....	309
Eaton and Kalamazoo Counties.....	310
Calhoun, Kent and Ionia Counties.....	311
Locations arranged by counties.....	312
Monroe and Lenawee counties.....	312
Hillsdale, Branch, St. Joseph and Cass counties.....	313
Berrien, Van Buren, Kalamazoo, Calhoun counties.....	314
Jackson, Washtenaw, Wayne, Macomb counties.....	315
Oakland, Livingston, Ingham counties.....	316
Eaton, Barry counties.....	317
Ottawa, Allegan, Kent counties.....	318
Ionia county.....	319
Clinton, Shiawassee, Genesee counties.....	320
Lapeer, St. Clair, Sanilac, Huron, Tuscola counties.....	321
Saginaw, Gratiot, Montcalm counties.....	322
Muskegon, Oceana, Newaygo counties.....	325
Mecosta, Isabella, Midland, Bay, Arenac, Gladwin counties.....	326
Clare, Osceola, Lake, Manistee, Wexford, Benzie, Grand Traverse, Leelanau counties.....	327
Ogemaw, Iosco, Alcona counties.....	334
Oscoda and Crawford counties.....	337

CONTENTS.

ix

Sec. 1.	Introduction—Locations by counties—Continued:	Page
	Kalkaska, Grand Traverse, Benzie, Leelanau, Antrim, Otsego, Mont-	
	morency, Alpena counties.....	338
	Presque Isle county.....	339
	Cheboygan, Emmet counties and Upper Peninsula.....	340
	Houghton county.....	341
	MARLS AND CLAYS IN MICHIGAN BY DELOS FALL.....	343
	Marl.....	343
	Michigan Clays.....	345
	Discussion.....	347

CHAPTER X.

METHODS OF AND COMMENTS ON TESTING CEMENT.

BY RICHARD L. HUMPHREY.

Sampling.....	359
Chemical analysis.....	360
Specific gravity.....	362
Fineness.....	363
Normal Consistency.....	364
Time of setting.....	366
Tensile strength.....	368
Constancy of volume.....	374
Conclusion.....	377

LIST OF ILLUSTRATIONS.

PLATES.

	Opposite page
Plate 1, Marl soundings 1, 2, 3, 4, 11a, 11b, by D. J. Hale.....	16
Plate 2, Horseshoe lake and soundings.....	48
Plate 3, Union City (Peerless plant) and Coldwater (Wolverine plant).....	104
Plate 4, General exterior view of an eleven kila plant.....	160
Plate 5, General plan of four kiln plant, with place for expansion.....	168
Plate 6, General interior view of slurry department.....	170
Plate 7, View of rotary.....	174
Plate 8, Front hoods of rotary kilns and clinker elevators.....	184
Plate 9, General plan of a three kiln plant, with elevations.....	184
Plate 10, Battery of Griffin mills, grinding clinker.....	184
Plate 11, Cross section of a Griffin mill.....	184
Plate 12, View in Newaygo Cement plant.....	190
Plate 13, General interior showing tube mills.....	196
Plate 14, A. Office building, with laboratories, etc.....	198
B. Stockhouse, with self-discharging bins under construction.....	
C. Bottom of concrete slurry pits under construction.....	
D. Dry marl deposit with hauling arrangement.....	
Plate 15, General exterior view of four kiln plant.....	198
Plate 16, Microscopically enlarged fragments and sections of Chara.....	220
Plate 17, Plan and view of Newaygo plant.....	240
Plate 18, Dam and raceway for Newaygo plant.....	240
Plate 19, Property and borings of Farwell P. C. Co. at Littlefield Lake.....	292
Plate 20, Map of Marl beds of the S. P. Cement Co., Athens, Mich.....	304
Plate 21, Silver Lake marl beds.....	320
Plate 22, General view of Newaygo Cement plant.....	324
Dredge excavating marl, Newaygo.....	
Plate 23, Index map.....	End.

FIGURES.

	Page
Fig. 1. Liquid marl sampler.....	11
" 2. Robert W. Hunt & Co., sampler.....	13
" 3. Sketch map of Hope Township, Cloverdale district.....	14
" 4. Soundings 28, 29, 31, 32 Cloverdale.....	115
" 5. Soundings 33, 34, 36, 37, Cloverdale.....	120
" 6. Soundings 36, 37, 38, 39, 40, 42, Cloverdale.....	121
" 7. Soundings 3 to 8 Pine Lake.....	127
" 8. Fremont Lake.....	135
" 9. Soundings 1 to 4, Duck Lake.....	142
" 10. Soundings at Central Lake.....	143
" 11. Section across North Island, Central Lake.....	144
" 12. Section across South Island, Central Lake.....	145
" 13. Rice Lake.....	152
" 14. Portage Lake, Onkama.....	155
" 15. Tube mill.....	173
" 16. Apparatus for filtering bicarbonate solution.....	201
" 17. Treadwell and Reuter's apparatus.....	213
" 18. Bottle.....	204
" 19. Isotherms and ground water temperatures of Michigan.....	216
" 20. Precipitated crystals.....	219
" 21. Plat of Raffeelee Lake.....	273
" 22. Plat of Runyan Lake.....	274
" 23. Plat of Mud Lake.....	275
" 24. Plat of Warren and adjacent lakes.....	276
" 25. Plat of Bush Lake.....	277

ILLUSTRATIONS.

xi

	Page
Fig. 26 Sketch map of Grass Lake, Zenith P. C. Co.....	284
" 27. Sketch map of Lakelands, Standard P. C. Co.....	289
" 28. Table of soundings of Standiford P. C. Co.....	303
" 29. Table of analyses of Standiford P. C. Co.....	304
" 30. Table of analyses continued.....	305
" 31. Sketch map of Cedar Lake and adjacent marl beds.....	323
" 32. Section of marl deposit near Houghton.....	341
" 33. Apparatus for determining the strength of mortars.....	355
" 34. Figures illustrating cement tests.....	356
" 35. Vicat needle, as originally designed.....	356
" 36. Modern form of Vicat needle and other testing apparatus.....	356
" 37. Tanks for the preservation of briquettes.....	370
" 38. Olsen Testing Machine, hand driven.....	371
" 39. The same, power driven.....	372
" 40. Fairbanks testing machine.....	373
" 41. Riehle testing machine.....	374
" 42. Result of tests of constancy of volume.....	376
" 43. The same, "pat tests".....	376
" 44. Diagram illustrating the relative strength of cement at various epochs.....	383

ERRATA.

Page 190, line 18, for Cederburg read Cederberg.
Page 277, the figure 23 is inverted.

CHAPTER I.

INTRODUCTION.

The grayish mud underlying our lakes and marshes has but very recently become one of the greatest resources of our state. On account of its position, being covered in most part by water or muck, it is not often seen and few people are familiar with its name or appearance.

Factory men have, however, after having become aware of its presence in such quantities in the state, made good use of it as a raw material for the manufacture of the best Portland Cement. A factory was started at Kalamazoo in 1872 (a description of its marl bed is found in Ch. V, Sec. 1). Here the old set or dry kiln process proved too costly and the site was abandoned. The first successful factories were started at Bronson and Union City. At the former place the marl was discovered by a section foreman who was sinking piles to support a railroad bridge which was to span the creek draining the deposit. The Bronson works use the Ransome rotary kiln wet process and the Union City factory, which first used the older style set kiln, are also adopting the wet process.

These plants have proved very successful and the interest among capitalists and landowners throughout the State has been intense to know more about the industry and how to gauge the true value of marl lands.

It will not be possible in the following pages to describe the raw material marl and its factory requisites so that any one may at once identify his marl bed as either worthless or specially fitted for cement manufacture. This comes only with the examination of many beds and the correct summing up of numberless possibilities all of which cannot be so minutely described as to be foreseen. The work of deciding on the final merits of a bed should be left where it belongs, with a specialist. The writer will then be satisfied if, from reading the following pages, landowners and amateur

prospectors can form a clear idea of what commercial marl is, how to go about prospecting for it, and how to decide correctly whether a given bed warrants a thorough examination for factory purposes.

Chapter II touches lightly upon other uses of marl. Much may be found in the early State and United States reports concerning these uses.

Chapter III discusses the adaptability of marl to cement manufacture.

In Chapter IV it is intended to give a description of as many views as possible of the origin of marl in the hope that there may be something of truth in one or all. Aside from its prime interest from a scientific point of view this chapter should afford some clue as to the location of marl beds and assist in their discovery by the explorer.

Chapter VII is intended to show both the magnitude of the cost and the numberless details to be calculated to a nicety by any individual or company embarking in the enterprise of cement manufacture.

Chapter VI gives many details which it is hoped will be useful to any one interested in the subject and shows somewhat the variation in mode of occurrence.

Credit is due to A. C. Lane, State Geologist, for his advice and assistance in the work throughout, also to Lathbury & Spackman of Philadelphia for their article and cuts of machinery. I also wish to tender thanks to the many men throughout the State who have assisted me in sounding beds and aided me with timely information.

Assistance was given to Prof. I. C. Russell in the preparation of his report on the Portland Cement Industry of the State, in the Twenty-second Annual Report of the U. S. Geological Survey, which he has therein acknowledged, but his report did not come to hand until this report was being read in page proof, so that we are not able to incorporate all the additional valuable information therein contained.

CHAPTER II.

USES OF MARL.

§ 1. Quicklime.

Marl has long been known in this State for its use in many different ways.* On the shore of many marl lakes there are to be found the remains of old lime kilns. These were erected for the purpose of burning the marl to lime. By a slow fire from beneath the organic matter was partly burned out and the carbon dioxide was driven off, leaving a fairly pure calcium oxide or the ordinary quicklime. Many log houses are still standing which were built with mortar of this kind or even with the unburned marl itself. But on a large scale this proved too costly a process compared with that later employed, which is the burning of limestone for lime. The reason for the greater costliness of the marl method is that the marl is really too bulky to handle with profit, for after the water is driven off there remains but little over half the original bulk as dry marl. From ten to fifty per cent of what remained after drying would then be burned as organic matter, implying a further shrinkage. On the other hand the limestone is more compact, has as a rule less organic matter, and is drier so that there is not the immense waste of fuel in driving off the water in the form of steam before the actual work of burning takes place. For these sufficient reasons limestone has taken the place entirely of marl as a raw material for the production of commercial lime.

§ 2. Fertilizer.

Marl is used widely as a fertilizer. New Jersey marl is very much more useful than ours on account of its valuable content of phosphorus. As the marl of Michigan contains little besides calcium and magnesium carbonates it has scarcely a commercial value for this purpose as the cost of transportation to any distance would easily exceed the value of the benefit derived from it as a fertilizer.

*Winchell, 1860, p. 131. See also Houghton's reports, 1838, p. 24; 1839, 1840, p. 94, etc.

Its real value, however, when in close proximity to the land upon which it is to be used, is often underestimated. Many beds of marl in this State were visited which lay very near to land which they would enrich, upon a judicious application, and the benefit to be derived from such application would have been greater than that from application to factory purposes. If marl is dug and allowed to lie over winter till it has been exposed to freezing and thawing, its lumpy tendency will be overcome and if then spread on a tough clay it will break it up and make it more easily cultivated. On the other hand, if it is to be applied to a coarse sand it will fill up the interstices of the coarser soil, rendering it able better to hold moisture and retaining humus which would, if allowed, accumulate, as well as other fertilizers which may be added. The chemical effect of marl is not described minutely, as much may be found written elsewhere on the subject. The effect, though slow in making itself felt, is very beneficial, as the lime of the marl gradually makes soluble for the plant the otherwise insoluble constituents of the soil. It must not, therefore, be taken for granted that, because a marl bed does not prove fit for the manufacture of Portland Cement, it is altogether useless to an agricultural community. Despite the amount of time and trouble so far devoted to the explanation of its value as a fertilizer its use for this purpose is not fully understood or taken advantage of.

§ 3. Minor uses.

There are several other uses for marl which cause but little demand. It is often used in tooth and scouring powder and as adulterant for paints. As these uses on account of the very small demand they could create for marl are of scarcely any commercial importance it is proper to pass on to its prime use in the manufacture of Portland Cement.

CHAPTER III.

THE USE OF MARL FOR CEMENT MANUFACTURE.

§ 1. Description.

The name "marl" is often heard but not with the precise meaning in which it is used in Michigan. It is a somewhat general name applied in different parts of the country to substances which differ in appearance and characteristics. Descriptions are given in the United States Geological Reports of extensive deposits of "marl" or "green sand" in New Jersey. These deposits occur in a distinct geological formation and contain the remains of animals and hence are rich in phosphates. They are called "green sands" from their color and are much prized on account of their phosphorus as fertilizers. The marls in North and South Carolina cover some two thousand miles area and like the New Jersey marl belong to a different geological era from ours. Another meaning of marl which more easily fits the term as used in Michigan is the name marl as applied to calcareous clays. In this sense of the word, however, half of Michigan could be called marl, for the light colored clays which form half our clay banks are calcareous or very rich in calcium carbonate. The indefinite or uncertain meaning of the term "marl" is very well illustrated by the definition as given in our dictionaries. "A deposit of amorphous calcium carbonate, clay, and sand in various proportions characterized usually by the most prominent ingredient; as clay-marl; shell-marl, a valuable fertilizer; green sand marl, a valuable mixture of green sand and clay."

The first step in the study of Michigan "marl"* should be to distinguish it carefully from the marls of other localities and from other formations closely allied to it in appearance and chemical composition. First of all our marl is nearly a pure "amorphous calcium carbonate." This is likewise true of several other similar

*More properly bog lime. L.

compounds. An amorphous calcium carbonate is a mineral compound, calcium carbonate, the particles of which appear not to exist in a crystalline form.* Chalk is an amorphous carbonate as well as limestone. The composition of pure marl, chalk, and limestone agree very closely, but they differ much in the tenacity with which the individual particles cohere and in their content of moisture. Our marl as now considered is much like the other two in color and grain, but is more bulky and usually contains more organic matter. On the other hand a very good example of a calcium carbonate which is not amorphous, but is crystalline, is marble. This has undergone changes which have made its molecules very tenacious of one another so that it would be too expensive to grind it into powder for the manufacture of cement as in the case of the materials before mentioned. The marl then, closely resembles in composition chalk and limestone and lacks with them the crystalline formation of marble,* although the last is a calcium carbonate. The four materials of like composition decrease in the tenacity with which their particles cohere in the following order; marble, limestone, chalk, marl. The last named, our own raw material, is then the most easily ground and, in that respect at least, much the easiest to pulverize for intimate mixture with clay in the manufacture of Portland Cement.

The marl of our State should also be distinguished clearly, not only from kindred materials, but also from other materials bearing the same name. It was above mentioned that the New Jersey and Carolina marls belonged to a distinct former geological period. Our own deposits as far as can be ascertained are distinctly of the present time and occur in an area limited by the former extent of the ice-sheet. They extend about the Great Lakes, being found in Wisconsin and both peninsulas of Michigan, extending northward into Canada and southward into Indiana and Illinois. It is not a continuous bed, but lies only in the deep pockets or holes and old drainage valleys left by the glaciers. As so far seen it has never been covered by over thirty or forty feet of modern drift.

Before it is studied further as definite a description as possible should be given of its appearance and composition with variations carefully noted so that it may be easily and certainly identified.

*But see notes on microstructure in the last chapter.

THE USE OF MARL FOR CEMENT MANUFACTURE. 7

It is often mixed with clay and the combination, a calcareous clay, is termed "marl." This usage does not give the meaning of marl as it is now used in Michigan in the cement industry,* but confuses it with clay with which it should be sharply contrasted. Again marl is found either mixed with sand, organic matter, or shells, to such an extent that its own characteristics are not clearly shown. It will therefore here be described as it exists in a fairly pure condition.

First it is found under lakes or swamps in the form of a mud consisting of from 25% to 50% moisture. In this condition it may appear dark gray, about the color of wood ashes, or nearly white. Upon drying it becomes much lighter in color. It coheres slightly and upon drying lumps much as does clay, but upon weathering breaks down into a friable mass. A very pure marl tastes much like chalk and often has a more granular appearance than the darker samples. As compared with the clay which is often found in its neighborhood it is much lighter bulk for bulk, and if each is stirred up in water the marl water clears much more quickly as its granular nature causes it to deposit first, while on the other hand, the particles of clay remain suspended in the water for some time before complete sedimentation takes place and the water becomes clear. Also upon the addition of an acid to two samples, one of marl and one of clay, the former will effervesce with formation of gas much more freely than the latter. The easiest way to distinguish marl from sand is by detecting the presence of grit. The particles of marl crumble easily upon compressing between the thumb and finger while fine sand feels hard. Shells, or their remains, are easily distinguished by their form and usually though not always form a greater or lesser portion of the marl. The greatest adulterant of marl, always forming at any rate a part of it, is organic matter. Its proportion can be roughly estimated by color of the mixture,—the darker the sample, the greater the percentage of organic matter. This may be sometimes so large that the marl becomes practically a muck or so small that it scarcely affects the pure white of the calcium carbonate.

As the contamination and consequent variation in appearance of marl is important to both manufacturer and scientist, its cause should be thoroughly understood. As stated in the definition, an

*Though correct enough in itself. The Michigan "marl" is more properly bog lime. L.

impure marl derives its name from the impurity which predominates. It has been stated briefly how to distinguish the true marl from each of its impurities when the marl and its adulterant exist as separate samples. Sand, clay and organic matter are not only found near the marl, but intimately mixed with it. The following analyses are those of three samples of so called marl taken from the same chain of lakes.

Insoluble.	Aluminum and Iron Oxides.	Calcium Carbonate.	Magnesium Carbonate.	Organic matter.
(1) 75.04	1.90	14.02	6.05	2.99
(2) 57.04	4.30	22.06	12.45	4.15
(3) 15.14	13.73	43.13	1.66	26.34

The measure of purity in each of the above samples must be found in the column under calcium carbonate. It is readily seen that all are very low and that each sample is very impure. The impurity in each case is, however, due to a different cause. No. 1 was largely sand, and in confirmation, notice the high per cent of "insoluble." Though of a marly nature it is full of grit, as could easily be detected by the touch. No. 2 is largely clay and has also a high "insoluble." It has besides nearly twice the magnesium carbonate of No. 1. The reason for this is that clays laid down at the same level as marls nearly always have a high per cent of magnesium carbonate as well as calcium carbonate, which increases the proportion of the former as compared with the percentage in true marl. No. 3 shows a more even distribution of the different impurities, but organic matter predominates. This appeared as a dark grayish muck and resembled but slightly a pure marl. It contains also 13.73% of iron and aluminum oxides so that it inclines somewhat toward a bog iron. It was found fifty feet under water.

In all of the above samples the marl has partly lost its identity, becoming in the several instances, a marly sand, a marly clay, and a marly muck. A careful examination of the color, grittiness, weight and effect of acid will soon reveal the true nature of the mixture and to what ingredient the contamination is due.

Fortunately for the factory interests of the State, marl is not often subject to such great variation in appearance and composition, but has somewhat definite characteristics of its own. Its

exact chemical nature together with its factory requisites will be considered in the final section in this chapter. All that will help the prospector to identify it on the ground is to know that it is generally somewhat granular in appearance, in color varying from that of dark ashes to dirty flour, is sticky and sometimes even soapy and greasy to the touch, and is distinguished from clay by its greater bulk and granular nature, from sand by the absence of grit (it usually contains a trace at least of quartz sand or diatomaceous silica), and from organic matter by its lighter color.

§ 2. General distribution.

The physical appearance of Michigan is necessarily of much interest to the prospector. Glacial action in past ages diversified the surface of the State and has left it ridged and hollowed thoroughly. Whatever may be taken as the agent of marl deposition, it is certain that these glacial valleys furnish the most favorable conditions for its existence and are its most usual resting place and that the present drainage furnishes the direct cause for its impurities.

§ 3. Prospecting tools.

The first thing necessary in prospecting is to get tools to work with. Several machines have been patented for the purpose, but as an owner usually wishes to sound only his own locality, the simpler and less costly the apparatus, the better.

The following is the description of a very simple outfit which is all that is necessary in the majority of beds. It must, however, be manipulated with care to obtain strictly trustworthy results.

1. Weld an ordinary two inch augur on a three-eighths inch gas pipe two feet long.

2. Thread the unwelded end of the pipe for coupling.

3. Cut three lengths of pipe each in half, or cut each into four equal lengths if it is desired to carry the outfit long distances. Thread the ends of the pipe for coupling.

4. Get couplings enough to couple all together making a continuous rod with an augur attached.

5. A "T" coupling must be inserted on the rod farthest from the augur and through this a rod or stick can be passed to turn the rod. A better way is to screw into each free end of the "T," a rod or a piece of gas pipe eighteen inches long. This makes a handle to the augur that can be inserted at any distance from the end. Usually a pair of Stillson wrenches are needed to untwist the pipe, which becomes very tightly connected during the boring.

Three-eighths inch pipe will be found to lift out much easier than half-inch, but will not stand boring to a great depth. If three-sixteenth inch is used it is liable to kink badly when sunk to any depth. On the other hand inch pipe cannot be thought of for the purpose as it would take a jack screw to lift the rod out. In the use of any size pipe or any style of sounding implement it must always be borne in mind that the quicker the work of sinking the rod, securing the specimen, and raising it is performed, the easier the work can be done. The reason for this is that the marl consists of finely divided particles partly suspended in water, making a mud. When the rod shoves aside these particles it takes them but a short time to pack around it. If it is withdrawn quickly before the particles assume their new position, about half the friction of marl against pipe is avoided and the work of withdrawal much lessened.

This is the simplest and most easily prepared and also the cheapest means of reaching the marl. Care must be taken to bore, twisting the handle as the rod is shoved down. It can generally be shoved through the mud with application of but little force, but if this is done the pod of the augur will remain filled with the surface marl which is first encountered in its descent and will bring that same marl to the surface again instead of filling with that at the bottom. Also the couplings must be very firmly started when each new length of pipe is added as the rod penetrates the marl. Many outfits are lost by the neglect of this little precaution. There is no reason why this simple apparatus should not do good work in most of the marl beds of the State. It can be made to penetrate a marl of medium consistency with considerable ease, requiring two or three men to run it. When the augur strikes sand at the bottom of the bed or in its course downward it can generally be detected by the peculiar grating sound and jar of the pipe in the hands of the operator. When it strikes clay the increased difficulty of boring is at once made manifest and it is well to immediately hoist the rod, as after boring a short time in the clay beneath the marl the apparatus will be freed with great difficulty. In deep borings care must be taken to keep the rod moving if possible, either up or down, as its recovery is easier.

This apparatus suffices for a fairly dense marl because the augur will clear itself of the surface drift on the way down and will retain fairly well the clean sample taken at the bottom. It will not,

however, take true samples where the grass or roots are very thick at the top and the marl is so fluid as not to be retained readily on the pod of the augur. In beds of this nature a different device will be required to obtain samples which will give a trustworthy idea of the center of the bed. A rather clumsy but efficient device has been used (Fig. 1), which is a remodelling of that used by Mr. Farr of Onekama.

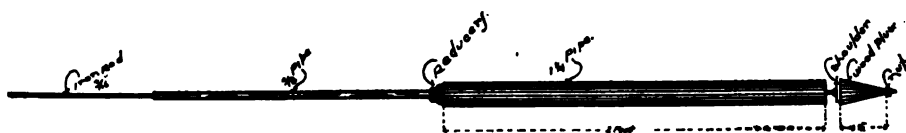


Fig. 1.—Farr's Liquid Marl sampler. For description see p. 11.

1. Cut a piece of inch gas pipe two feet length.
2. Thread one end of the same.
3. Screw reducers on the threaded end till the last reducer can take a half or three-eighths inch pipe.
4. If no time and materials are at hand to make a disk to close one end of the large pipe the following effective but clumsy device may be used: Upon the end threaded according to direction, screw three-eighths inch pipe of any desired length to form the rod.
5. Sharpen the open edge of the inch pipe and fit into it a plug with a shoulder that fits against the rim, allowing the plug to penetrate a half inch into the open end of the inch pipe.
6. Sharpen the end of the plug opposite the shoulder and bore a hole lengthwise through the plug.
7. Pass a three-sixteenths inch iron rod through the plug from the shoulder end and bolt it by screwing a nut upon the end opposite the shoulder, which end should be sharpened so as to more easily penetrate the marl.

The end of the rod may be threaded for several inches and a nut first screwed on, then the end of the rod passed through the plug and the nut on the end screwed tight against the plug. This will hold the plug from being shoved up the rod by the force of the thrust against the marl, and the nut on the end will prevent the plug being pulled from the rod.

The rod with the plug securely fastened on the end is then inserted in the open end of the cylinder formed by the inch pipe and is passed up through that and the three-eighths inch pipe which has already been screwed to the upper end of the inch pipe. The free end of the rod may project through the pipe at the upper end.

When placed in the water the apparatus is in the form of a long rod of three-eighths inch piping, at the lower end of which is a cylinder of inch pipe. The lower end of this is closed by the plug which fits easily against the lower end of the cylinder by the shoulder already described. This plug is manipulated by means of the iron rod to which it is firmly bolted, which runs up through the hollow rod to the operator above.

Method of Operating.

The plug is first held firmly against the mouth of the cylinder by means of the rod. The whole apparatus is then shoved down the desired length. The pipe is then raised, the rod being held stationary and after raising the rod is then shoved down to its former level, being shoved tightly against the shoulder of the plug. In this position both are then raised to the surface, the plug shoved out by means of the rod, and the sample taken from the cylinder. This takes a perfect sample to a depth of about 18 feet and can be rigged in a short time at any good hardware store. It is cumbersome on account of handling the long iron rod, but is perfect and very trustworthy for any marl not too solid to be penetrated by this means. The plug keeps all grass, roots, silt and foreign matter from the cylinder while it travels downward, and after the sample is taken, the plug being again shoved against the mouth of the cylinder, excludes all foreign matter during the ascent of the sample.

A slot could be devised to close the mouth of the cylinder, and divide it into two halves. This could be made to rotate when the cylinder was at the desired depth and allow the marl to enter, and then being rotated half around again, could close the orifice while the rod ascended. This is not a contrivance that could be fitted out in a few minutes, but when once made would be much less cumbersome as dispensing with the iron rod. This apparatus is easily made and can be relied upon to give perfectly satisfactory results.

One other must be mentioned and that is one invented and manufactured by Robert G. Hunt & Co., Chicago, Ill. It consists of a piece of steel about 18 feet long and much the shape of the half of a long gun barrel slit longitudinally. The end which first enters the marl is capped and pointed with steel so that it will penetrate more easily, and the other is surmounted with a handle for raising. The two edges running lengthwise are sharp so as to cut the marl.

When the instrument has been shoved to the depth desired it is turned half around, filling it with a clean swath of marl its whole length. When it is withdrawn there is a perfect sample of the bed from top to bottom and any portion of it can be sampled if desired. It is not suitable for liquid marl as the sample would run out before the apparatus could be raised to the surface. A device for very fluid marls will be found described in the account of the operations at Cloverdale.

§ 4. Location of marl.

With a general idea of its location and the means at hand for sounding, the question next presents itself, "Where is it most likely to be found?" As has been said, marl is found in the hollows or glacial valleys that scar all parts of our State. Its more definite

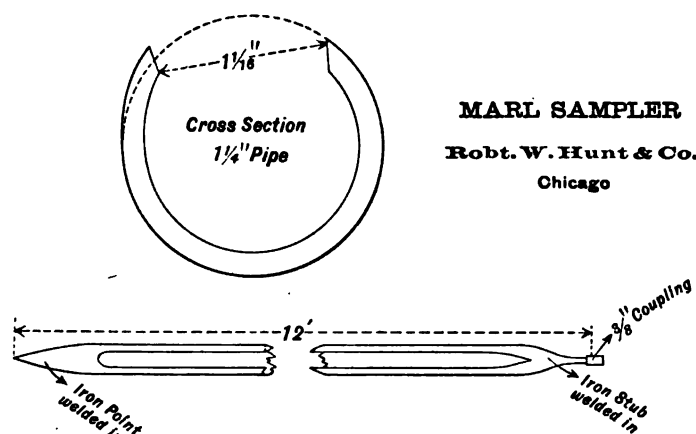


Fig. 2.—Hunt Marl Sampler.

location is a puzzling and interesting study. The facts so far ascertained will here be given, but the theory of its origin which they seem to sustain will be given in Chapter IV.

1. Marl is always found in some place that was originally covered with water.* The water level of Michigan has fallen within recent years so that the old water lines of lakes can be easily traced even by the casual observer. The marl therefore is not confined to the immediate vicinity of present existing bodies of water. It underlies dried up swamps sometimes a thousand acres in extent and the banks of what now appear small streams are solid marl. However,

*Somewhat similar subaerial deposits are known as calcareous tufa or travertine. L.

upon noticing the comparative depth and altered course of such a stream, and its source when the low lands through which it flowed were all covered with water, its banks often prove to have once been the bottom of a large channel or lagoon. Often, also, a large swamp can be easily identified as the bottom of a large dried up lake.

2. The next point of interest is that the water above marl is

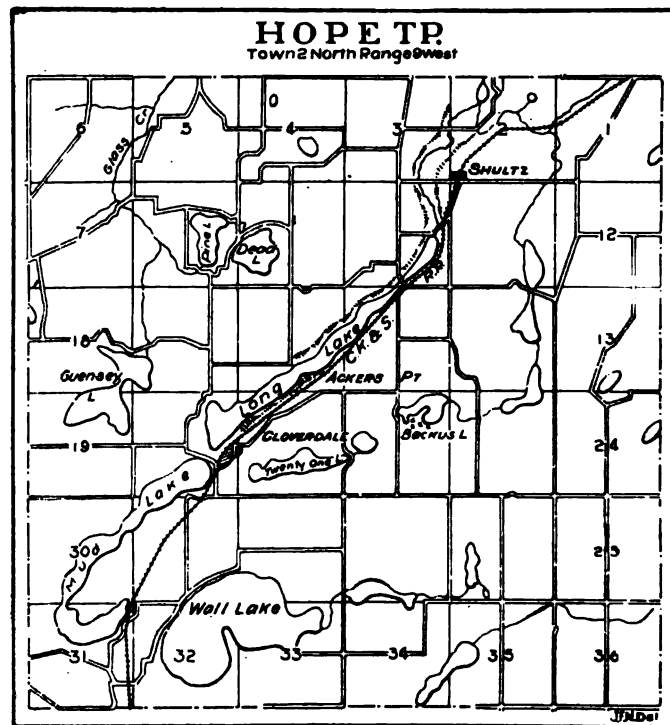


Fig. 3.—Map of Cloverdale district. By a mistake the r in Guernsey is omitted. Sec. 18. The lake on Sec. 22, is properly Balke or Horseshoe Lake, the name given being an error in the county atlas.

usually hard, containing first of all calcium and magnesium carbonates in fairly large proportions.* In the Cloverdale region (Fig. 3, Chap. VI, Sec. 2) the general observation of people living about the lakes was that the marl is found in a hard water lake, but not in one containing soft water. A half day's sounding in Mud or Round Lake yielded but one sample of very organic marl a few feet in depth and lying in mid-lake under ten feet of silt. This was a lake with very soft water while the water of one a few hun-

*See analysis of water in description of Peninsular plant. L.

dred feet from it, which contained 20 to 30 feet of marl, was hard. Little Lake (Chap. V, Sec. 7) contained nothing but silt and did not even respond to the hard water test.

3. A fact closely connected with the foregoing is that hard water springs are everywhere found in close connection with marl lakes. One striking example of the converse of this fact was noticed at Escanaba. There both springs and marl were said to be absent, and flowing wells were tapped only at great depths, though the district was solid limestone.

4. The presence of water and its hardness both being somewhat related to the presence or absence of marl another closely related and interesting study is the comparative level of marl lakes and those lakes or depressions in which marl is absent. As there could be found no reliable contour maps showing the levels of different points in Michigan an aneroid barometer was tried, but it was found that only those lakes contiguous to each other could be at all accurately compared. The results of these comparisons agreed very well and served in the end to establish a somewhat general rule, that of two depressions, the one most deeply indenting the surface of the land, will contain the marl. It is also true that the deeper depression will contain the harder water, provided it cuts the deeper water bearing strata of subsoil. This conclusion was very often verified in the hilly country where the surface is deeply cut by streams and lakes. It is also quite generally the rule in comparing adjacent marshes for the presence of marl. Still it must be considered dangerous to conclude that a deep depression always forms the basin for the hard water bearing strata about it, as these same strata may slant away from, rather than toward such a basin.

No general rule can be formed which will guide the prospector unerringly to the presence of marl. As the marl is in nearly every case covered by finely deposited sediment, muck, other marsh growth, or water, its exact location and depth can be determined only by actual soundings made through its covering. Still the guides here given have proved rather useful in the absence of any other helps whatever, and as simple results of experience must not be taken as fixed rules.

5. In a chain of lakes the marl is generally deeper and of better quality in the lakes toward the head of the chain. Where the head lake has had no large body of water or stream other than a spring

stream opening into it, the marl appears of purer quality and with less of foreign matter overlying it than do any of the lakes below it. In two of the chains of lakes so noticed the head lake formed the first of the series and so lay that there never could have been any other natural drainage than the one in action at the present time. This rule works well in the case of a series of two lakes, the upper one of which is fed by springs. The marl lies bare and of greater depth to the upper end of the upper lake, and sediment above the marl, if it occurs in large quantity, is liable to be in evidence toward the lower end.

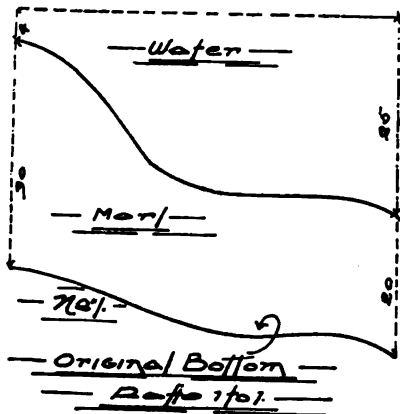
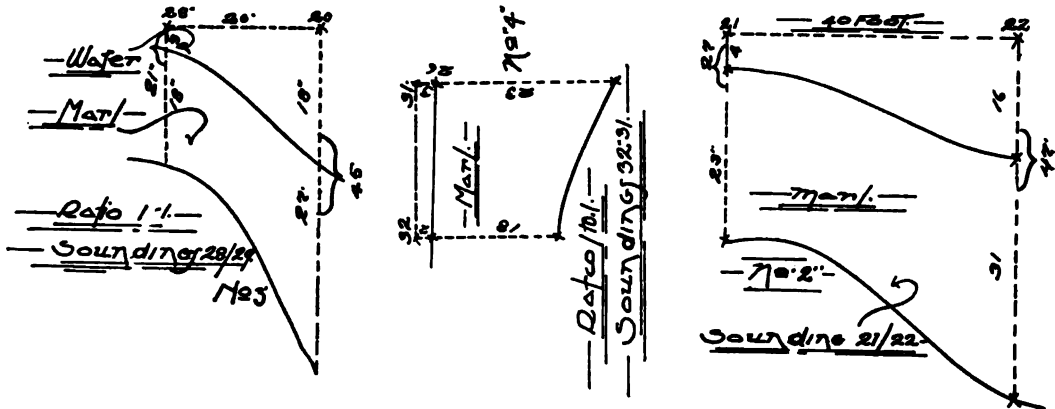
6. In a large lake or one unevenly and thinly underlain with marl the deepest marl is often found in bayous or indentations of the shore-line. In such cases the marl generally thins very rapidly to the deeper portions of the lake.*

§ 5. The distribution of marl in a single bed.

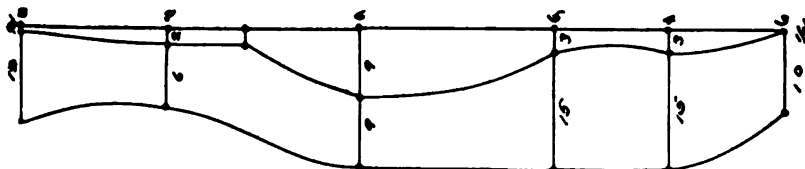
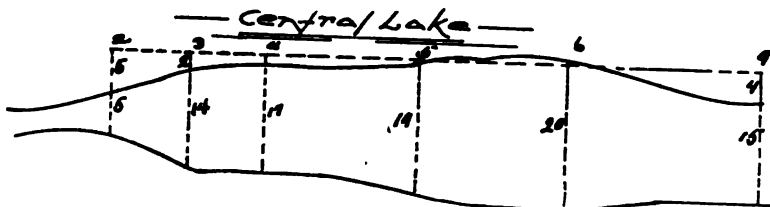
In the consideration of this subject much depends upon the stage of the deposition in which the bed to be sounded exists at the time. For marl beds exist in two different states. The first is the dried up lake or marsh, the second, the hard water lake where the marl is still depositing.

In the old lake bed or marsh the marl deposit is basin shaped. It generally has one or more centers toward which the marl deepens regularly. The marl has evidently deposited as long as water remained. As the marl reached the surface or the water dried down to the surface of the marl or both, vegetation started upon the shallows and sealed the deposit over very evenly. Where the lake bottom proper was even in the first place, the marl deposit is very regular. This was shown in some old dried up lake beds of the Upper Peninsula where the deposit was laid down evenly, increasing from the outside edge two feet in depth, to the center twenty-five feet. It is the rule and not the exception in marshes entirely covered by vegetation and containing no open water, but underlain with marl. It must be remembered that many of our inland lakes and marshes have their bottoms, uneven in their nature, cut and seamed with terraces, kettles, and holes left by receding glaciers. In the evening or blanketing process of marl deposit these holes are leveled over. In such cases the depth of marl can be calculated with only general accuracy and the above rule can scarcely be verified. A fair illustration of even deposit would be that at Central Lake in Antrim County, Plate I. See also Chapter

*See description of Onekama Lake.



Central Lake
Map of North Island
No. 11.B.



MARL SOUNDINGS, 1, 2, 3, 4, 11A, 11C.

VI, §16. An illustration of uneven deposit or better uneven depth caused by sudden variation of contour of lake bottom would be the lakes sounded at Cloverdale (Plate I, Diagrams 1 to 4).

It is very often the case, however, that the marl bed does not cover the whole depression formed by the original lake bed or by the marsh as it appears at the present day. In such a case the main body of the marl forms a basin of its own which is liable to lie as at Portage Lake, Onkama (Fig. 14), in an indentation or nook of the greater basin forming the marsh. It may or may not lie near the deepest portion of the original basin. The sealed marl bed is on the whole the more regular in its increase and decrease in depth, and is, excepting in the case or exception of an uneven original bottom, regularly deepest toward the center of the deposit.

In the lake where the deposit is still continuing or just being discontinued, the variation in depth is markedly the opposite.

In this condition the lake is nearly always surrounded by a fringe of shallows containing the deepest and purest marl. In deep water the marl may be much shallower, may cease entirely or may be a marly muck, the first and third named conditions prevailing in nearly all cases in deep water.

In studying this second condition it is found that marl forms most rapidly in shallows or about points. This was strikingly illustrated at Long Lake, near Cloverdale. This was being cut into two different bodies of water, by decrease in depth of water and at same time by rapid growth of marl, which was 33 feet in depth in the narrows at Ackers Point. Thus Horseshoe or Balker Lake was being cut into two lobes or basins and the marl was very deep at the narrows connecting and on the points of marl growing out to separate the lobes. Nearly every actively growing marl lake represents three stages or steps of growth, the shore or marsh of marl bed grown to water level and sealed over by marsh growth, the actively depositing marl of the fringing shallows, and the deeper parts which are more slowly filling up with a cruder and more impure marl. Eventually the fringe of shallows will grow to the surface or far enough for rushes to catch organic matter to form a solid covering of growth. As the center of the lake grows shallower with increased depth of marl the marl becomes whiter and deposition more active, the marl fills to water level and is sealed like the former fringe of shallows. We have then from the second condition a growth to the first condition; a completed and preserved marl bed.

When the water was higher during the deposit of the shallows marl* the shore marl will have deposited to a higher level than that in mid-lake. When sounded we often say that the "surface" is deepest at the center, when in reality the marl was deposited to a second lower water level and then filled in with marsh growth to nearly the level of the shore fringe of shallows. In such a case it is noted that the shallow marl is of much finer quality because it was deposited in shallow water while the marl in mid-lake was deposited in deep water, and this latter was suddenly brought to the surface by a fall of water level and covered with an organic blanket preventing a finer deposit.

In deposits of the second or uncompleted condition the gradation in quality, due to the variation in content of organic matter, is often very marked and seldom absent. The shore shallows unless very deep deposits, are the purest, then as soundings are made toward the center the bed decreases in thickness and the marl decreases in quality, organic matter steadily increasing at the expense of the calcium carbonate.

Below are given a table of soundings in lakes about Cloverdale, pages 78, 79, 80 and table of analyses made of samples taken, page 80. On page 82 is a list or key to all the samples of marl elsewhere taken, of which analyses were made. On page 83 are the partial analyses of these samples. It will be seen by consulting the table that several samples are marked A and B. The samples marked A were taken near the bottom of the bed and those marked B were taken at the surface of the bed directly over the first sample marked A.

Owing to the fact that the deposits were very heavily adulterated with clay and sand it is difficult to compare for increase of organic matter.

TABLE OF SOUNDINGS, CLOVERDALE DISTRICT.

No.	Analysis.	Location of Sounding.	Depth of water.	Depth of marl.	Bottom.
<i>Long Lake.</i>					
1	1A....	In Narrows at Ackers Point.....	2	30	Tamarack log on bottom.
2	1B....	Surface of above.....			Gravelly sand.
3	2A....	100 yards east of No. 1.....	4	17	
4	.....	Same as above.....	.....	10	3 ft. into fine sharp sand.
5	2B....	Same as above. Sampled at surface.			
6	.....	200 yards east of No. 3.....	24	10	
7	.....	Sand of No. 6. Not preserved.....			
8	3A....	Shallows 200 yards southeast of No. 6.	4	30	Very fine sand.
9	3B....	Surface of No. 8.....			

*As for instance at Cedar Lake in Montcalm County. L.

THE USE OF MARL FOR CEMENT MANUFACTURE. 19

TABLE OF SOUNDINGS, CLOVERDALE DISURICT—Continued.

No.	Analyses.	Location of Sounding.	Depth of water.	Depth of marl.	Bottom.
10	4	About center of lake.....	25	20	Heavy gravel.
11		Surface of above.....			
12		At lower narrows.....	6	12	
13		East of rocky islet.....	4	9	
14	5A	Beyond No. 12 toward outlet.....	3	33	Heavy gravel.
15	5B	Surface of No. 14.....			
16		To side toward springs. Marl sandy.....	2	2	
17		In narrows.....	2	10	
18		Surface of No. 17 not preserved Muck sample of No. 6 taken near here.....			Pepper and salt sand.
21		Northwest of rocky islet.....	4	23	
22		Fishing hole.....	16	31	
23		Just outside of narrows north of Ackers Point.....	2½	17	Fine sand.
24		Half way between Nos. 22 and 23.....	2	17	
25		200 yards south of No. 23.....	4	25	
26		At point of lake opposite Cloverdale.....	3	25	
27		Opposite springs issuing beneath blue clay at end.....	3	25	
28		Just below boxed spring (x).....	3	18	
29		20 feet out from No. 28.....	18	27	
30		Just west of Cloverdale, south side.....	4	23	
31		Opposite Beechwood Point.....	3	23	
32		Shallows in toward Beechwood Point.....	2	17	
<i>Balker or Horseshoe Lake, Lobe Next to Outlet.</i>					
33		In front of narrows at lower end.....	2	23	
34		In narrows.....	2	30	
35		Shore opposite landing.....	3	27	Gravel.
36	11	Up lake on slight point.....	3	29	
37		Just outside of No. 36 in deep water.....	13	15	
38		In straight line across slight neck to south shore.....			
39		Sample can No. 5 of water taken over No. 40.....			
40	9	Deepest sounding made. Brought up trailing water plant which had powerful odor of polecat*.....	50	10	
41		At mouth of large boiling spring 200 feet toward outlet from point on south shore marking previous line of soundings. No. 4 collected at this spring.....	0	32	muck.
42		200 feet west of 41 at the end of series of soundings across lake.....	2	37	Marl dark blue.
43		Toward upper end of lake from No. 42.....	2	27	
44		At outlet of lake. Jar No. 9 taken at surface.....	½	32	
45		Center of basin. Jar of water No. 6.....	10	30	
46		In inlet from other lobe, forming narrows.....			
<i>Guernsey Lake.</i>					
47	15B	Blue clay flats at narrows.....	2	4	muck.
48		In west channel or arm of south lobe.....	8	30	
49	12A	West shore of shallows.....	6 in.	27	
50	12B	Surface of same.....			
51		30 feet out from 49.....	5	24	Sand bottom.
52	13B	Surface of No. 51.....			
53	14A	100 yards south or up from No. 51.....	4	20	Sand.
54	14B	Surface of No. 53.....			
55	15A	Bottom of Mud Lake.....	33	5	
<i>Pine Lake.</i>					
1	16	Cove of landing at lower end.....	3	20	
2	17	In front of boiling spring on opposite side.....	6 in.	10	
3		In outlet.....	6 in.	10	
4		First line across narrows.....			
5	18	Out from No. 4.....	3	15	
6	19	In line across.....	9	9	
7		In line across.....	2	6	
8	20	At farther side.....	6 in.	12	

*Chara foetida (?). L.

ANALYSES OF CLOVERDALE SAMPLES.

Number.	Insoluble in HCl.	Al ₂ O ₃ . Fe ₂ O ₃ .	CaCO ₃ .	MgCO ₃ .	Organic Matter.	Remarks.
1A.....	3.34	2.55	84.30	3.18	6.68	Long Lake.
1B.....	2.35	2.94	82.11	2.64	9.96	
2A.....	2.95	.04	85.00	4.62	6.39	
2B.....	1.84	2.00	81.00	10.21	4.95	
3A.....	20.54	2.30	67.53	3.48	6.15	
3B.....	75.04	1.90	14.02	6.06	2.99	Sand and gravel.
4.....	11.70	3.92	69.30	3.17	11.91	
5B.....	14.15	1.18	75.15	.....	.....	Mg. precipitated.
6.....	32.32	4.62	42.14	2.91	18.01	
7.....	18.04	2.70	40.00			
9.....	15.14	13.73	43.13	1.66	26.34	Balker Lake.
10.....	4.64	2.00	65.09	3.28	24.99	Balker Lake.
11A.....	57.04	4.30	22.06	12.45	4.15	Mostly clay.
12B.....	7.20	1.25	64.12	2.38	24.06	Guernsey Lake.
13A.....	55.10	6.80	25.28	3.10	9.74	
13B.....	13.70	2.24	65.00	2.72	16.34	
14A.....	61.10	4.50	21.00	11.76	1.64	Clay and sand.
14B.....	1.44	.90	84.50	4.19	8.97	
15A.....	41.94	3.80	47.23	3.79	3.24	Clay.
15B.....	66.64	5.36	16.60	9.53	2.88	Checked volumetrically
16.....	11.97	1.45	75.62	3.44	7.52	Pine Lake.
17.....	1.80	.80	83.00	2.38	12.02	
18A.....	5.04	1.84	74.46	2.31	16.35	
18B.....	3.06	.96	85.04	4.20	6.75	
19A.....	D. 34	2.00	88.43	2.42	7.81	
19B.....	2.04	1.84	84.46	2.83	2.83	
20A.....	3.55	3.50	80.18	3.33	9.44	
20B.....	1.24	1.60	88.30	3.03	5.83	
21.....	9.70	10.90	71.00	1.92	6.48	
Kent 16.....	.14	.73	90.30	3.21	4.82	

For position and depth of samples above analyzed see preceding table of soundings of Cloverdale region.

LOCATIONS OF SAMPLES COLLECTED FROM DIFFERENT PARTS OF
THE STATE BY D. J. HALE AND ANALYZED BY A. N. CLARK.

No. 4. Marl from Big White Fish Lake. Springs emptying near contain iron and sulphur.

6. Marl of Lime Lake, 17 feet below surface of bed.

7. Shell marl at surface of same bed (Lime Lake). At first pure white, it turns brownish red upon exposure to the air.

12. Marl near spring at Corinne. Very hard and difficult to bore in with ordinary augur.

13. Marl at Wetmore in bottom of boiling spring.

18. Central Lake. Head of lake. Deep sounding.

19. South end of lake, 27 feet deep. Below level of bed.

21. In channel S. E. of S. Island, Central Lake. (Intermediate Lake.)

25. Center of Mound Spring.

26. N. side of Mound Spring.

28. 10 feet below the surface of Mound Spring, Central Lake.

29. Clay on Clout's farm, Central Lake.

30. Low clay west side of Central Lake.

31. Mixed strata of clay in brickyard at Central Lake.

32, 33 and 34 are three depths of clay on a side hill near Central Lake.

32. The highest layer consisting of broken down shale or clay.

33. Shale below 32.

34. Lowest shale.

37. Black shale from a sixty foot shaft west of E. Jordan 4 or 5 miles. Shaft was mined without success for coal.

38. Green shale lower in level than black shale of sample 37.

37. Iron from north side of Mound Spring, Central Lake.

THE USE OF MARL FOR CEMENT MANUFACTURE. 21

PARTIAL ANALYSES OF SOME OF THE SAMPLES COLLECTED FROM DIFFERENT PARTS OF THE STATE BY D. J. HALE AND ANALYZED BY A. N. CLARK.

Number.	CaCO ₃ .	MgCO ₃ .	Fe ₂ O ₃ . Al ₂ O ₃ .	Insoluble.	Remarks.
4.....	23.57	1.89	6.75	56.95	Red sandy marl.
6.....	92.00	0.57	.....	.....	Very white. Ferrous iron, 70%.
7.....	90.00	.30	.....	.....	Brown on exposure to air. Fe 0.72.
12.....	76.07	1.59	1.00	19.00	White.
13.....	90.71	1.51	1.60	4.50	Cream color.
18.....	42.32	2.04			
19.....	57.32	1.51			
21.....	90.90	1.59			
25.....	32.76	1.89			
26.....	27.32	0.53			
28.....	1.09	1.73			
29.....	.18	1.05			
30.....	4.82	1.51			
31.....	20.18	1.40			
32.....	.36	1.66			
33.....	.44	.98			
34.....	1.25	1.89			
37.....	3.21	1.96			
38.....	2.00	2.42			
27.....	85.00	1.13	5.65	.....	Red shale.

Above samples were analyzed by acid solution the same as for marls and limestones. The method gives too low results for CaO where samples consist mostly of clay.—A. N. Clark.

Upon comparison of the eight double samples marked A and B, page 20, it will be found that five of them show an increase of organic matter of the deep soundings over the surface soundings.* If the surface samples are taken directly at the surface they are liable to show greater organic matter due to the presence of roots of grass and rushes in shallow water, as these generally form a thick somewhat impervious mat over the surface of a bed of shallows. If soundings or samples 6 and 7 above are compared, it will be seen that both are high in calcium carbonate and that the surface marl is more impure than that at a depth of 17 feet. This was a shell marl bed and may form an exception to the rule that the deepest marl has less of carbonate and more of organic matter. This rule cannot be too much emphasized as it forms one of the few guides in the examination of a typical marl bed. If the marl all lies under deep water it will vary little in content of organic matter being nearly the same at the bottom as at the top. Such was the case in the bed at Rice Lake, which contained a bed 35 feet in depth and yet the marl did not vary as much as in many smaller lakes, remaining about the same at the bottom as at the top. On the other hand a chain of small lakes was examined which had marl in the shore shallows 30 feet in depth. It

*As also in analyses furnished by Michigan Portland Cement Co. L.

was nearly pure on top, but at bottom was scarcely more than a muck.

In lakes where the deposit of marl is continuing at present or has only recently ceased, the conditions governing its location are highly interesting. In such cases it appears to have covered the lake bottom evenly like a sediment, but with this difference, that it is a sediment that fills in and helps very much to do away with inequalities in an uneven lake bottom. This was very strikingly illustrated in the series of soundings at Cloverdale given above. (See also Chap. V, Sec. 2.)

In a marl lake which is depositing at the present time there will be seen little if any black sediment. The common river or lake alluvium or sediment that will naturally accumulate is surrounded by the white particles of marl and forms a part of the marl bed, but of course loses its dark color, becoming light in color like the remainder of the bed. Twigs, limbs of trees that fall into the water, the water plants themselves that die and would naturally become black and so color the bottom, are surrounded by the white marl particles and are transformed into a part of the bed. When this process is in active operation the bottom of the lake shallows is perfectly white from the transforming power of the forming marl. The prospector can readily trace out the point at which this process has ceased by the presence again of sediment on the lake bottom, giving it its customary black color. And this symptom is a satisfactory and sure index to the variation of the marl bed. Where sediment has begun to form, instead of being coated by marl, the marl will decrease in depth beneath as the sediment increases in depth above, and where there is any great depth of sediment above there will be found little marl beneath it.*

The position of this lake sediment must, however, be thoroughly understood. It lies under the water and above the marl and when it begins to cover the marl, it is pretty good evidence that the bed has ceased growing. When the bed on the other hand, from any cause such as the fall of the water level to the surface of the bed or the growth of the bed up near to the surface of the water, gives marsh growths, etc., a chance to form on the surface of the bed, growth will stop and the bed will become sealed over and forever afterward will be a part of a marsh or dry lake bed, assuming at once the condition spoken of under dry lake beds.

*This is illustrated also by soundings near Riverdale, Gratiot Co. L.

It has been already stated that the edges of lakes where marl is at present forming contain the deepest marl. It is true that the rule in regard to these lakes is decrease of depth toward the center, for the marl is not at the present day forming as well in deep water as in shallow. Its quality toward deep water decreases by virtue of increase in per cent of organic matter. This seems a reliable rule with few exceptions and has been found so true as to be depended on in almost every case. The marl rapidly deteriorates till in very deep water it becomes little more than a mucky marl or perhaps a bog iron. The marl at this depth exists in a fine state of suspension and could be taken only with an instrument so tight as to hold water as well as marl. A sample was taken in fifty feet of water while at the sides of the lake a few hundred feet distant there were twenty-five to thirty feet of fair marl. In this short distance with sudden increase to a great depth the marl has become almost a muck losing the characteristic light color of marl.

The presence of springs, while characteristic of a marl region, has nothing to do with the depth of marl at a given spot. Though the presence of hard water in and about a marl lake is expected as a rule and may generally be calculated upon, a spring is no guide whatever to the location of the deepest marl. One spring will be found to bubble through marl many feet deep while another spring in the same lake and containing water fully as hard is as likely to be surrounded for any distance by pure sand, or to issue from the ground through pure lake silt or through muck. If anything, the balance of instances is against marl near springs as they, if not in the lake issuing from marl, start small rivulets of water which, as the outlets of the springs, bring down a slight drift of sand or other foreign matter. In highly charged hot water mineral springs such as may be easily found in the Rocky Mountains or in Europe, the minerals contained in the water are upon its arrival at the surface immediately released from solution and thrown down as a deposit at the mouth of the spring. The method of deposition and the location of such deposit is obvious. Our springs certainly do not discharge their burden of lime immediately and therefore give no sure clue to the manner in which the deposit is brought about or to the whereabouts of the marl deposit.

§ 6. Surroundings of marl.

It is of the greatest practical importance to the prospector to note carefully the surroundings of marl. In the definition and

identifications of marl attention was called to the immense variation in appearance and chemical constitution of marl brought about by the impurities with which it often becomes contaminated. In the surroundings of marl the prospector must always seek the direct source of these impurities and it is for this reason that the location of marl in relation to its surroundings must always be carefully noted.

(a) Shore wash. Marl can never be considered as a deposit occupying very large single areas as do many other minerals. It is confined to those depressions which have once formed lakes and are now lakes or marshes. It then fills a pocket or hollow of the above description and is directly subject to the natural forces that act upon the hills and banks forming the rim of the depression which is nearly always the shore line of the lake. If the indentation is deep the shore line will be a bluff of clay or sand. If the marl and the water which must have originally covered it extend up under or close to the commanding bluff, the action of rain or running water can be nearly always traced in surface wash upon the marl, for gravity will then bring down upon the marl which is in process of formation, large quantities of sand or clay, depending upon whether the bluff is sand or clay. The presence of sand may still be expected even when the banks of the lake are very low, providing the deposit of marl is very deep. The reason is this. If we consider that a marl bed 30 feet in depth is stripped from a lake we have a valley originally thirty feet deeper than the one which lies before us filled with 30 feet of marl. Still in case of very low banks the deep marl bed was always covered by water and the slant of the bank alone will do much to govern the amount of sand or clay washed down upon the bed. In such cases, if a deep marl bed terminates abruptly at the foot of its bank or bluff, the deposit will be found to be thoroughly mixed with the wash of the overhanging bank. Soundings in such cases reveal a layering of sand then a layer of marl and then of sand and so on to the bottom. Or it may appear from the shore to some little distance out that there is nothing but sand. Upon sounding it is found that the sand and gravel from the shore have swept down and over the marl completely covering it for some distance out, the marl in some cases being found to terminate very abruptly against a steep bank and underneath a covering sheath of sand. This is the immediate and very local effect of the banks or shores of the lake upon the appear-

ance and constitution of the marl bed about its edge, but in such cases the marl is rather thoroughly mixed with sand or gravel some distance out and is entirely unfit for manufacture. A lake with steep banks or with marl lying close under low banks must be watched closely for local traces of mixing. Long Lake at Cloverdale is an example of this.

(b) Streams. The next contaminating agent is running water. A stream running through a sandy or clay ravine upon a bed of marl in a lake can generally be traced for some distance by the presence of sand, muck, silt and other foreign substance in the marl. In many cases the formation of marl seems to have been prevented entirely. But on the other hand the course of streams changes rapidly, as does the drainage of many lakes, so that a stream is often found flowing over marl which has been already formed, very likely before the stream existed at that point. If a stream coming from another lake flows over marl all the way and comes from a marl lake its evil effects as a sand bearer are very slight. If it comes with considerable force from a sandy region and has been rather permanent it produces a large patch of sand for some distance about the inlet, and there is an entire absence of marl. Small rivulets and ditches formed or dug in recent years across a marl bed, carry in their path large amounts of sand and even gravel, which sometimes render the marl unfit for use. They should be watched with great care by the prospector to see that they do not bring impurities in quantities sufficient to destroy the value of the marl. Marl when once formed in a rather solid bed is not easily penetrated by sand bearing waters. Springs which bubble up through marl beds from a sandy bottom beneath do not often cause the sand to permeate the bed in large amounts. The sand brought by streams flowing over established beds does not penetrate the bed to any great depth provided such a bed is rather solid. If, however, the sand bearing agent, such as a stream or wash from hills, has been at work layering or steadily mixing with the bed at all depths during its formation, the bed will be found to be mixed with the adulterating sand or gravel for long distances, sometimes completely destroying the commercial value of the deposit.

(c) Surface. This is a name used to designate the covering of the marl, whatever that may be. The first covering of marl has always been water. It is formed under water and it is necessary

as long as it grows that it be destitute of all other covering. Exception or explanation must accompany this statement. The natural clothing of a marl which is in active growth is generally a characteristic water plant* growing on the marl. This covers large areas in the usual marl shallows, and is seldom found lacking in an actively growing bed. It is small, lying close to the bed, reclines and almost trails and has very bare branches which issue from the stem in whorls or circles completely surrounding the parent stem. These plants, together with all other objects not possessing the power of motion, are thickly covered with a whitish coating of the marl. This condition of active formation of marl ceases when the shallows approach the surface of the water so closely that rushes and marsh growth of all kinds can obtain a foothold on the marl as a soil. The marl then becomes coated with a surface of muck and marl deposit ceases. When the marl rapidly dries out there remains but a thin coating of marsh growth which may remain as only a few inches of soil surmounted by ordinary marsh grass. There is then practically no surface or one which may be easily removed by the dredge. If, on the other hand, the surface next to the marl remains very wet, it is conducive to a very luxuriant marsh growth which may sometimes consist of from two to seven feet of loose roots and rushes. Sometimes a thick wood has sprung up on the bed consisting of trees of large size or a very thick tangle of underbrush. This means a tough surface of roots to be removed before the marl can be used and its nature should be carefully noted by the prospector. This is one way in which a marl bed is covered and gets its surface.

(d) Silt under water. When the conditions have become unfavorable for further formation of marl, the silt which is constantly deposited from lake water, ceases to be enveloped by the particles of marl and falls upon the bed, making a dark covering. This sometimes forms over a bed or a part of it and the growth then ceases. In time the deposit of silt reaches the surface of the water or the water sinks to that of the silt. In either case the silt is exposed so that marsh growth gets foothold and seals the deposit as before. One marl bed was found where there were layers of this silt with its attendant marsh growth intervening between layers of marl. The rule is in nearly every instance, however, that when sediment of the nature of silt or marsh growth is found be-

*Chara, see chapter by C. A. Davis. L.

neath the marl such a layer is an indication that the bottom of the bed has been reached.

(e) Lining of marsh growth or decayed plant life. It is true that pure lake sediment often smothers and seals the growth of a marl, even when the bed is covered with many feet of water. There is another very interesting phenomenon which the prospector notices when he has penetrated often to the bottom of some beds. Just before the sounding apparatus penetrates the sand or clay underlying the bed, it passes through a thin layer of nearly pure organic matter which seems to be the finely compressed and decomposed residue of plant life. It is green or blue in color, fine in texture, and it forms a very sharply defined layer a few inches thick. It lies just under the marl between the marl and sand forming an organic lining. It contains some lime and does not effervesce very freely with acids. This layer was noticed in several rather deep deposits.*

(f) Organic matter permeating deposits. Remains of plant life always form a characteristic part of a marl bed, but the prospector will find a more or less sharp distinction between two kinds associated with the bed:

(A). Organic matter of the marl deposit.

This organic content of the marl bed varies with the depth of the bed and the depth of the water above the marl. It is as much a part of the marl bed as is the content of lime. It can be depended upon that this content of plant remains will increase in two ways; first, from the shallows toward the center of a lake or marsh, and second, from the surface of a thick deposit toward the bottom of that deposit. This is one of the rules with fewest exceptions and will serve as one of the best practical guides to the prospector. This rule works, of course, only in the absence of outside influences; i. e., when the composition of the bed is not interfered with by drainage, water streams, etc. The consideration of this leads directly to that of

(B). Organic matter of drainage.

When a stream brings in much silt or drift of any kind the conditions favoring the deposit of marl cease to exist, then a heavy admixture of organic matter follows with no fixed rule by which to judge it except perhaps direction and force of the water which may empty upon the deposit. In the majority of such cases the dividing line between marl and foreign matter is sharp enough so

*Compare what is said about Schizothrix. L.

that the area of the marl can be fairly outlined. Yet this sometimes varies and the influence of the foreign organic matter is felt for a varying distance into the body of the marl deposit.

(g) Materials underlying marl. The various soils which surround and influence the quality of the marl bed have been described and it now remains to describe the substratum or foundation upon which the marl lies. The thin layer of organic matter which often forms the lining of the bed has already been described.

In Rice Lake, at the bottom of thirty-five feet of marl, a thin layer of pure organic matter lay under the marl and rested upon sand. This layer was pierced in nearly all soundings in the lake, where bottom was struck.

Marl never lies on muck or organic matter of any great depth. The usual foundation is sand or clay. The majority of beds lying upon clay seem to indicate that the marl is a distinct deposit differing from clay and that if the clay is mixed with marl to any extent it is due to a sedimentary deposit of the clay by water flowing off of some adjacent clay bed. Instances were seen where, in this way, clay of a highly magnesian composition was freely mixed with the marl deposit. In most cases there is, however, a sharp line of division between marl and clay.

Perhaps the most characteristic material which forms the final basis of marl deposits is sand. This is in nearly every case a fine quartz sand which may be mixed with fine grains of mica, forming "pepper and salt sand." If the deposit of marl is lined with the above described layer of organic matter the material, whether it be sand or clay forming the basis or foundation for the marl, does not work into the deposit affecting the uniformity of its quality. If coarse gravel takes the place of the fine sand bottom it indicates the former presence of flowing water and foreign matter of all kinds so far described must be watched for by the prospector.

A fact in this connection is noteworthy. This is that an amount running from 1% to 3% of fine quartz sand is fairly well distributed through most deposits of marl. This seems to be strictly separate from the ordinary surface washings of coarse sand. In one case, Onekama Lake, the sand of this special kind was nearly absent. But on the bottom of the deposit and in some cases at intervals toward the surface, there were thin layers of half decayed organic matter. In some cases the wood, at 10 or 15 feet beneath the marl, was well preserved so that the fibre could be split. In one instance

at Ackers Point, Cloverdale, a well preserved tamarack log was struck at the depth of thirty feet. It lay on the bottom of the true lake bed as a sounding near by showed sand at the same depth.

(h) Materials overlying marl. It is difficult to judge of the age of a marl bed by its covering. Large areas of marl are covered by marsh. This generally is in a semi-fluid condition so that it jars with the tread for yards around. It will remain in such a condition as long as the water level allows the water to stand within a foot or so of the surface of the marl. In such a condition the marsh growth of rushes and their roots grow rapidly and surface soil, etc., is caught making a spongy growth of sometimes five to eight feet or more in thickness. Solid ground may form over it and the presence of marl be unsuspected. When, however, a shaft is sunk or railroad spiles are driven, or a grading put on the ground, the presence of marl is attested. The spiles sink suddenly or the grading sinks, or the shaft is suddenly filled with mud. All these things have occurred, showing that the marl is often buried deeply. In such cases the water at the level of the marl kept it fluid all the time. A surfacing of marsh growth develops rapidly and leads one to think the marl very old on account of the thickness of the surface upon it. On the other hand, if water level sinks, the marl dries out and no luxuriant vegetation grows excepting the ordinary marsh grass. There are hundreds of acres of this that may be very much older than that covered by marsh growth. At Rice Lake there was a marsh growth of from two to six feet which must have been largely grown since the lake bottom was drained but a few years ago.

§ 7. Method of prospecting a given area.

The general rules for the location of marl beds by the prospector have been given. Also those more particular laws which will assist in judging of the probable effect on the bed of foreign materials surrounding, above, around, and beneath the bed. After a marl bed is located in a valley or depression, either as a lake or marsh or combination of both, the next step is to estimate the area and depth. If a surveyor's outfit is to be had the work can of course be performed with unquestioned accuracy. Lines may be run measured distances and at right angles to these, another set of measured lines making of the marl a checker board of squares the intersecting lines of which should be fifty to one hundred feet apart. At these intersections soundings could be made and the

depth noted upon the plat of the bed. As it very often happens the prospector does not carry surveying or measuring instruments, a practical and at the same time accurate method of testing the bed must be devised, as follows:

(1) A record of everything done must be kept and this record must be made as soon as each fact is ascertained, not trusting to the memory any detail.

(2) Soundings must be made as nearly as possible in straight lines with the lines parallel to each other.

(3) The best and most permanent marks by which to locate the soundings made and the work done are the section lines and boundary lines of landowners. A bed can usually be located as included within boundaries of a quarter section or of a forty or eighty acre plat of ground.

(4) To measure the distance between soundings, the woodman's method of pacing the ground can be resorted to. Soundings should be made at first not over fifty feet apart, but if the deposit, after many soundings, is found to be very regular in both depth and quality, the distance may be increased to one hundred or two hundred feet, care being taken to at once decrease the distance between soundings upon the slightest signs of change of quality or sudden unevenness in depth.

(5) If soundings are entirely upon land the distance is more easily calculated, but if on water and in summer it is more difficult to determine accurately. In making deep soundings in shallows on water it is safest to use boats. A rough frame or planking will serve to bind the boats together and the soundings may be made between the boats, the operators standing upon the cross planks as nearly as possible at the center. It is often found possible, where the bed is not very thick, for the soundings to be made with augur and pipe from one boat, the boat being rocked by the persons in it to exert a leverage on the side in raising the pipe. This sometimes fails, resulting in inability to raise the pipe, which becomes stuck in the marl. It must always be remembered that small pipe and quick handling make light work.

§ 8. Commercial importance of composition.

It will now be well to consider marl in regard to the manner in which its chemical composition affects its usefulness for factory purposes.

In the following treatment the impurities of marl will not be

considered but the fairly pure marl only, leaving out sand, clay, and extraneous organic matter. The best marl and that which should most nearly typify marl as an economic deposit lies, we will say, in a small inland lake. It is covered by but a few feet of water and by no silt or foreign matter whatever. It is growing at the present time. It rests on a bed of fine quartz sand, which does not affect its composition to any great extent. The influx of surface waters and drainage streams has not interfered with the purity of the deposit. This lake is fed mainly by hard water springs. Such are the surroundings of a very pure marl when it is in the process of deposition.

(1) Appearance.

The marl on the shoals or marl flats of such a lake is very white and somewhat granular. The marl near or not quite at the surface is very much the purer and will generally give the higher analysis if it is not mixed with roots of water plants in gathering the sample. We see such high analyses of marl quoted frequently as 95% to 98% calcium carbonate. This is all true enough, but represents usually but a small portion of the bed which in reality would average much below such a percentage if the analysis of a sample from the bottom of a thirty foot bed were to be given, even if the deeper sample were to be taken over the same spot as the shallow. Marl of the above location, at the surface of an actively depositing bed is often very granular and even gritty to the touch. Upon a careful examination it will be found that the grit is composed entirely of marl and not of sand, as might at first be supposed. The marl is seen gathered into pebbles and has often formed about roots and small objects of every kind. When the root has died and rotted down it often leaves a hollow pebble around which the marl continues to form.* Toward the bottom of a thirty foot deposit, at the same place, few if any of such accretions will be found present. The marl is at the same time finer grained, more adulterated with organic matter and darker in color. Toward the center of such a bed, in deeper water, the marl is also darker in color at the surface, the concretions disappearing also. It is this reason that single chemical analyses reveal little of the nature of a bed. As far, however, as the exact nature of marl and its identity as distinguished from every other calcareous deposit are concerned, a pure bed as above described serves as the best illustration of one

*Produced by Schizothrix. See C. A. Davis' paper. L.

very important fact to the manufacturer, which is that marl as a distinct deposit and free from all contamination varies very much in its own composition, in the same bed at the same spot.

(2) Composition.

With the foregoing understanding an endeavor will be made to explain the composition of marl. Marl is certainly due to one clearly defined agency. (1) It derives its composition from the carbonates contained in the hard water of the springs. It is not deposited immediately around the springs. A secondary agent in the deposition is the growth of shells, snail shells, bivalves, etc., which have died leaving their shells to more or less increase the depth of the calcareous deposit of marl. In places favorable to their growth, or where they have been sifted from the surrounding marl by wave motion they form a nearly solid bed, while in other places they and their broken down forms are nearly if not entirely absent. The following are the analyses of fairly pure samples of marl from different parts of the State.

MARL ANALYSES.

	Calcium Carbon- ate.	Magne- sium Carbon- ate.	Ferric Oxide.	Alum- ina.	Insolu- ble Silica.	Soluble Silica.	Mois- ture.	Organic Matter.	Sul- phuric Acid (SO ₃).	Phos- phorus.
1	74.480	0.50	2.36	0.54	7.20	.....	1.25	12.88	0.89	
2	82.142	4.620		0.9775	1.151	.....	16.27	11.173	0.00	0.037
3	89.965	1.872	0.999	0.158	1.222	.....	9.750	5.984	0.00	0.03
4	83.045	1.201	Undeter- mined		3.569	.....		11.700	0.485	0.00
5	87.000	0.910	1.30	0.070	0.780	0.130	0.600	9.800	0.270	
6	97.000	1.010	1.250	0.08	.....	.....	.....	.....	.30	
7	94.496	1.250	.....	0.482	.....	2.528	0.235	0.790	0.00	0.150
8	92.91	1.89	0.53	0.21	.....	1.54	2.01	0.80	trace.	
9	77.1	3.28	.....	1.92	9.64	.....	.....	10.99		
10	92.1	3.2	.....	.76	.....	.22	.....	3.7		
11	60.00	3.00	.....	0.62	.30	.....	24.60	1.50		
12	.....	.....	.10	.14	1.90	.....	0.64	5.69	.56	.01
13	98.8	.....	.....	.....	0.73	.....	difference	1.17		
14	92.79	2.27	.....	0.52	3.25	.....	.....	.....
15	93.75	2.42	.25	.55	1.01	.18	difference	1.84	trace.	
16	91.34	.77	.40	.55	.78	.42	.....	5.79	.26	

KEY TO PRECEDING TABLE.

1. Marl from Alpena, Mich., W. E. Courtis, analyst.
2. Marl, Cass City, Michigan, same analyst.
3. Marl, Cass City, Michigan, same analyst.
4. Marl, Grass Lake, Michigan. This sample was dried at 100 degrees centigrade, dry residue 42.11%. Undetermined 3.569. Same analyst.
5. Near Grayling, Michigan. Average sample when dried lost 61% of its weight. Same analyst.
6. Same sample, but figured without organic matter.
7. From lake shore near Grand Rapids. This sample loses 6.376% of water and volatile hydrocarbons when heated to 100 degrees centigrade. The silica is not sand. The 0.235 moisture is combined water. Phosphorus as tricalcic phosphate. It also contains chlorine as sodium chloride, 0.119%. Same analyst.
8. Marl from Alpena, Michigan. Total 99.87.
9. Grass Lake, Michigan. Was collected by A. C. Lane and analyzed by F. S. Kedzie.
10. Marl at Peninsular Plant, Cement City, Goose Lake, Mich. Total 99.98.
11. Marl at Cedar Lake, Montcalm County. Not dried. Analyzed by F. S. Kedzie.
12. Marl near Grayling, Michigan. M. A. C. bulletin 99; CaO 45.16, MgO 0.32; K₂O 0.37. Dried marl is 49% of original weight of sample.
13. This sample is the same marl as 11, but a different sample and figured dry. The marls as taken contained 9.95% water. F. S. Kedzie analyst.
14. Naubinway marl. World's Fair report, p. 132.
15. Light marl, Michigan Portland Cement Co., H. E. Brown, chemist.
16. Blue marl, Michigan Portland Cement Co., H. E. Brown, chemist.

Additional analyses will be found elsewhere in the report under the descriptions of individual deposits, by reference to index. See also table of tests.

Nearly all of these samples are very high in calcium carbonate and are well fitted for the manufacture of cement.

(3) Interpretation.

In the first place the percentages as here seen represent but a small portion of the bed as it is gathered in sampling. On the other hand it does not represent the true proportion of compounds which enter into the composition of the finished cement. The sample, as shown in many of the remarks in the key given above, is, when received at the laboratory, evaporated to dryness, so that water evaporation during analysis will not affect the final percentages by the steady loss of weight of the sample which would continue to dry. In evaporating to dryness a sample generally loses from 40% to 60% of its weight, or in other words, a bed of marl as it lies ready for prospecting is at least half water, which must be lost in the process of manufacture. With this understanding each compound above named will be considered separately.

Calcium Carbonate.

This is the one necessary compound to be considered in the manufacture of the cement. It should be at least 90% of the dried sample. The calcium carbonate is derived by some agent from the hard water of the lake above or at one time above it.

It is pure white and largely influences the color of the whole sample of marl depending upon the percentage of it contained. In the process of analysis the calcium carbonate is separated into two most ordinary compounds. In analyses given out from a laboratory these are often stated separately, a percentage of calcium oxide and one of carbon dioxide being given, part of the carbon dioxide belonging originally to the magnesium carbonate. In such a case the easiest way to get from the stated analysis of the sample the percentage of calcium carbonate is to add to the stated percentage of calcium oxide 78.577 of itself. We will have, within a very small fraction of a per cent, the amount of calcium carbonate which the calcium oxide represents.

In the process of manufacture as well as in that of analysis, the calcium carbonate is broken up into calcium oxide and carbon dioxide. The carbon dioxide, which is a gas, passes off as a smoke and is not of any use in the finished cement, which should be free from it. It follows from this that after the 50% or 60% of water is driven off, 44% of the percentage of calcium carbonate is lost as gas and does not enter into combination in the finished cement. The all important compound CaCO_3 enters the factory in a wet, finely divided state, best fitted for mixing it most easily with clay,

is dried, then heated, expelling the carbon dioxide and leaving it as calcium oxide surrounding the other finely divided particles of clay which contain the silica to be made soluble by the action of the intense heat of the rotary kiln.

Magnesium Carbonate.

This is a compound analogous in many ways to the calcium carbonate. As seen in the above analyses it exists in the marl in very small percentages. This is the case when the marl is pure. A large percentage of magnesium carbonate in marl as pure as the above would not be characteristic of marl as a deposit. It would show generally that some clay had become mixed with the marl. For in such cases, when clay is laid down at the level of marl or during the deposit of marl, it generally contains a larger per cent of magnesium carbonate than does the marl,* and so influences markedly its composition. In such cases the percentage of insoluble matter, or silicates and aluminates is much higher than in the marls given above, on account of the increase in per cent of silica in clay over that in the natural marl, which of itself would contain a low per cent of silica. The magnesium carbonate has not been found to add to the real value of the marl, and it is certain that if it is present in any large amounts it will be a positive detriment to the finished cement. As the marl will vary from day to day in its content of organic matter and other components it is well to have the dangerous elements as much as possible absent. It must also be remembered that one of the greatest troubles is too much carbonates in clay. For this reason if for no other the marl should be low in magnesia. As seen, however, in the above analyses the purer marls are nearly free of magnesium carbonate and it seldom causes trouble in samples with a very high calcium carbonate content.

Ferric oxide and alumina.

These are very likely deposited as ferrous hydrates in the marl bed. As such they are nearly colorless. When, however, a deep sample of very white marl is brought to the surface and exposed to the air for some time it may turn to a red or brownish red tinge from the oxidation of iron. These are seldom deposited in the marl in amounts to cause trouble. A case has before been pointed out where a marl with high content of organic matter showed also a very large percentage of iron and aluminum oxides. This fact is

*See analyses of clay given elsewhere in this report and in Part I.

remarkable, that an intensely iron spring may discharge its highly mineral waters at the edge of a very pure marl bed. The grass about the spring will be covered with oxidized iron showing a red slime or even a bog iron effect, but the marl itself is not influenced in the slightest. It will generally be noticed that marls with the highest organic content also contain the highest percentage of iron and alumina.

Insoluble and soluble silica.

The per cent of insoluble silica is traceable to several sources. First of all, nearly all beds contain fine quartz sand independent of the ordinary coarse drainage sand and pebbles that may be washed into the bed as already explained. This sand can sometimes be found to permeate the bed from top to bottom, even when the bed is thirty feet deep. If, however, there is a very even layer of the organic lining above referred to, the sand does not seem to penetrate as well, if at all. The sand will be found in the purest beds to vary from a fraction of a per cent to several per cent in amount. This is in the case of a comparatively pure marl. In case a clay has at any time mixed with the bed the content of insoluble silica will vary, but will remain larger together with other disturbing features, such as the increase in magnesia before mentioned. Sometimes such a condition will produce an increase in content of magnesia toward the bottom of the bed, while in a pure bed little if any regular variation of magnesia has been discoverable with increase in depth from which sample may have been taken.

Soluble silica.

The marl is intimately associated with the remains of plants, no matter how pure it may be or at what depth it may be sampled. The same may be said in regard to shells although samples have been found where the shell formation could not be traced. It is certain that plants, especially diatoms in the course of their growth, render a very small amount of silica soluble. This of course would remain in the body of the marl after the death of the plant. Certain shells are said to have the same power. The amount of silica in a good marl is very small. The soluble silica will not be in amount to help or hinder greatly, for, as may be seen in the analyses cited, it is but a fraction of a per cent. The insoluble silica is, however, higher in per cent and it is that which must be watched closely. It ought not to exceed three or four per cent for the reason that it interferes with the balancing of the silica and

calcium content of the slurry and prevents the best burning of the mixture. Insoluble silica as sand is one of the most refractory substances known. It is not as finely divided as clay silica, does not make as intimate a mixture with the lime of the marl and does not flux so easily. Although sand marl cement can be made, sand is entirely out of place in the process used in Michigan, and should be guarded against carefully in the selection of raw material.

Organic matter.

Organic matter is a necessary evil in relation to marl. It is of no positive harm except that it increases the weight and bulk of marl without adding to it its usefulness. It is burned out as nearly as possible in the manufacture of cement and all that remains is ash. As noticed in the sample above given, where the calcium carbonate content falls suddenly it is nearly balanced by increase in organic matter. It has already been explained how profoundly organic matter influences the character of a bed. The law of its own variation can be depended upon to hold true where outside agents have not also contaminated the bed. It will also be noticed that in the very pure samples where organic matter is nearly absent the marl has but a trace of other compounds beside calcium carbonate and that where it increases in a large degree, all the elements already mentioned spring into prominence again. If, then, marl is very free from organic matter it is liable also to be free from dangerous compounds. If it is high in organic matter it will be bulky to handle, will not yield a large percentage of calcium oxide for the production of cement, and will necessitate continual watching for fear of dangerous compounds.

Sulphuric and phosphoric acids, chlorine, etc.

These compounds, if present in large quantities, would be dangerous. They cause little trouble unless the marl is highly organic when, as before explained, it is of little use anyway. Sulphuric acid is often present in dangerous amounts in otherwise commercial marls. In the above samples some have been given in full and then figured without the organic matter. This is not a true representation of the real value of the sample as it exists in the marl bed and is not intended as such. Care should be taken to discount the high and flattering percentage of calcium carbonate shown by such an analysis. This reconstruction of the real analysis is made to determine whether or not the dangerous elements would, in the burned marl, exist in sufficient quantity to forbid its use. The per-

centages exist in such reconstructed analyses as they would enter into the formation of the cement and directly influence its formation. Perhaps, this one fact should be borne in mind, that in the new proportion of compounds brought about by burning, the carbon dioxide derived from the carbonates of calcium and magnesium is driven off also by the heat before the marl has reached the proportions which it possesses upon incipient vitrification. In order then to give the truest percentage estimate of the marl as its component parts would exist when ready for use, the analyses should be figured with both organic matter and carbon dioxide absent.

Having noticed the various ingredients and their variation, the final question to the prospector is fitness of marl as shown by analyses. The sample, not the bed, is suitable if it contains 90% or over of calcium carbonate and no dangerous element in large proportions. If the marl runs over 90% of calcium carbonate it is not liable to have other ingredients in dangerous proportions, provided the bed is a characteristic deposit, not mixed with any of the adulterating foreign matters before mentioned. As a matter of fact it would be hard to find a bed, all samples of which are above 90% calcium carbonate of depth or extent suitable for manufacturing purposes. The reason for this is the steady variation of organic matter before mentioned.

§ 9. Location and size of bed.

Besides quality of the marl there are other points worthy of notice. Is the bed located on a railroad or one of the Great Lakes? If it is found necessary to build a railroad to the deposit, the extra cost must be reckoned, compared with competing raw material more favorably located. If the bed is located where vessels can easily reach it from the Great Lakes, it has one of the best natural advantages.

The expression has often been heard, upon the sounding of a small bed of marl to the depth of 15 or 20 feet, "Oh, here is marl to last for years." Besides quality and location, the size is the third vital point always under consideration, and one which the owner should be able to determine himself. To illustrate the point clearly, the changes which the marl undergoes up to the time of partial vitrification, will be reviewed as nearly as possible.

The marl as it lies in ordinary swamp consists of from 40% to 60% by weight of water. First this water must be evaporated from

the slurry and then whatever organic matter is contained in the marl must be oxidized, burned out, passing away to remain functionless in the finished cement. Still another important shrinkage in volume and weight must take place. The remaining useful calcium carbonate is also oxidized, losing 44% of its weight in the form of carbon dioxide, which passes off as gas with the smoke of the kiln. Shrinkage or gain in weight of the other ingredients is slight on account of their small percentage.

Take for example, sample No. 5 of the foregoing analyses.

- (1) 100% less 61% equals 39% dry marl.
- (2) 87% of 39% equals 33.93% of original wet marl as calcium carbonate.
- (3) Calcium oxide is always 56% of a given weight of calcium carbonate.
- (4) 56% of 33.93 equals 19% of original weight of wet marl as calcium oxide.

Of sample No. 5, but 19% therefore of the weight of the sample as it was taken from the marsh, enters into the final weight of finished cement as an active cementing agent. Nearly all of the remainder passes off as useless gas or as water requiring great expense in heat to evaporate it. While this sample is rather low in calcium carbonate, probably the very best samples of fairly wet marl could not show above 25% calcium oxide available after burning. This has a direct bearing upon the question of area and depth of marl necessary for cement manufacture. The estimates given by the factories in active operation in the State, figure $1\frac{1}{2}$ to 2 cubic yards of marl as equal to one barrel of Portland Cement. This would vary according to the purity of the marl and the amount of water contained. The water is a necessary evil; by the wet or slurry process there must be enough water so that the marl will mix and pump readily, though, after mixing all the water must be evaporated in the burning which requires expense in fuel. Taking $1\frac{1}{2}$ cubic yards as the equivalent of one barrel of cement it will be well to calculate the consumption of an ordinary fourteen rotary mill.

- (1) $1\frac{1}{2}$ cu. yds. equal 40.5 square feet of marl one foot deep.
- (2) 14 rotary mill produces 1000 barrels cement per day.
- (3) 1000 times 40.5 equals 40,500 cubic feet of marl per day consumed.

(4) 43,560 square feet equal to one acre.

(5) Dividing 43,560 by 40,500 we find there are 1.0755 days work in an acre one foot thick.

(6) In 200 acres 200 times 1.0755 equal 215.1 days work. This is about the number of days the factory would run out of a year. If the deposit were 25 feet thick, such a deposit 100 acres in area would run a 14 rotary factory 25 years. Such a rate of consumption of raw material seems enormous and according to this estimate there are few single beds of marl that would furnish raw material for a length of time to guarantee the erection of a plant. Certainly a strip of marl 75 to 100 acres in area would scarcely warrant the erection of a large mill. The largest cement corporations in the State buy all the marl in a given vicinity comprising several lakes. In considering the largest area of bed for one factory it must be remembered that marl cannot be transported any distance to a factory. The factory must be located on or very near the bed. The immense shrinkage in volume of marl during process of manufacture has already been shown. The expense of carrying marl any distance cannot be met when competing with other factories located on their beds and with the immense limestone districts of other parts of the country.*

In conclusion, a marl must be of the best and the most uniform quality, it must be free from its natural adulterants, it must be located near some waterway or on a railroad, must be 15 or 25 feet in thickness over an area of several hundred acres. Such qualifications all included in one vicinity, are very difficult to find. High quality throughout, unlimited quantity, and fine natural location are necessary, for a good article must be manufactured and shipped easily and cheaply and upon an enormous scale to make the manufacture of marl a very paying and useful industry in the State.

*Compare, however, what is said concerning the Hecla Portland Cement Co.

CHAPTER IV.

THEORIES OF ORIGIN OF BOG LIME OR MARL.

§ 1. Introduction—the various theories.

An effort will be made to give all the ideas obtainable upon this phase of the subject. It is fact and no more than natural, that every one who has examined marl deposits has some one view as to the origin of so peculiar a resource. With the knowledge the prospector now has of the nature of marl it would be very helpful to arrive at a correct conclusion as to the origin of marl deposits. This would rapidly aid in pointing out the most probable location of the marl and would prepare the explorer somewhat beforehand as to the exact quality of the marl and would inform him as to the necessity of a more or less minute examination of different parts of the bed to pass upon its fitness for practical purposes.

A scientific conclusion in regard to the origin of marl is also a small contribution to the exact knowledge of the geology of the State of Michigan and as such should be of permanent scientific value. In the hope that out of many opinions the truth will finally come, space is given in this place to all views obtainable upon the origin of marl. Prof. Davis's work on the subject is given a separate chapter (Chap. V), while the others will be stated as clearly as possible under this heading.*

(1) Shell theory.

The idea has often been expressed by those who examine a bed that shells are the origin of marl. There are certainly beds that verify this statement. Some are beds of nearly solid shells, and shells too that are well preserved to a depth of fifteen or twenty feet. In such cases, no doubt, the location of the bed has been especially favorable to the formation of shells. Samples of shell formation from Florida have been seen where the shells formed a

*Some farther suggestions, and observations, microscopic and otherwise, by me, will be found in the last chapter. L.

calcareous mass of shells and their broken down remains, very similar to the purely shell marl of our own State.

(2) Sedimentary theory.

This theory is that the lime existing as it does in our State in fine particles distributed through the soil, was washed by the action of the water from the pebbles and limestone rock of the State during the glacial period. That after the ice had melted the limestone sediment of finely ground rock was washed into the drainage valleys left by the ice in melting, and formed a fine sediment much like a clay, but being of a different density than clay, was deposited separately, forming the beds we now have.* This idea was suggested by H. P. Parmelee.

(3) Chemical theory.

This theory, one that was found to be held by many chemists of the State, is at least, a very plausible solution of the cause of the formation of marl. It is based on this fact or principle in chemistry. Carbon dioxide by its presence in water aids it in holding in solution a greater amount of calcium and magnesium carbonates. The minerals are held in the form of double carbonates of calcium and magnesium. When a water containing carbon dioxide under pressure and a larger amount of the carbonates than it could otherwise hold in solution without the presence of the carbon dioxide escapes from confinement underground, and is exposed to the air, the carbon dioxide as a gas, escapes and the carbonates, no longer held in solution by the presence of the gas, are precipitated as simple carbonates of calcium and magnesium. There is no doubt whatever that such a reaction takes place in many instances which can be cited in nature. The idea here held is that all the conditions are correct for such reaction. The water of our springs is confined in underground waterways, or better, reservoirs. The gas cannot escape and is under pressure. The carbonates washed from the soil and lime rock are in the water and in solution as evinced by its clearness. When the spring flows out from beneath a hill the water spreads out in the calm inland lake, is released from pressure and perhaps warmed, and the gas escapes, and the carbonates are precipitated to the bottom in the form of a marl. Such is this popular and striking theory. It has much to recommend it. Some if not all the conditions named are

* Or possibly where the rock was practically all limestone, the glacial rock flour might be almost wholly composed of calcium carbonate. L.

present. The cases in nature where such change undoubtedly takes place are to be found in our mineral springs of the West and Europe, and in calcareous tufa of our own State. The heavy mineral springs are surrounded at their very openings by the minerals precipitated from them as the waters issue. In most of these cases the process of precipitation has been aided by the cooling of the waters which are very hot. Hot water such as these contain will also take into solution a much greater percentage of minerals.

From the above comparison it will be seen that though minerals are somehow precipitated in both cases, the conditions are not exactly identical and it would be dangerous, therefore, to reason from one to the others.

The conclusions reached in the search for an origin for marl deposits are much the same as those reached by Prof. Davis in his report, which is given in full in Chapter V. The endeavor will be made in the following pages to show wherein the several theories above named point to the real causes of the formation of marl, and also to record the steps taken to test the relative value of the same, as made in the special survey of the State requested of me by the State Geologist.

§ 2. Shells.

Shells form a greater or less part of a marl bed. Their presence is sure evidence that they are an agent in the origination of a bed. An analysis of pure shells from a marl bed shows that they help to form the purest part of the bed and that the proportion of their compounds as compared to that of a very pure marl without shells is very nearly the same. They are, however, but a minor agent in the formation of most beds. Their existence and plentiful growth depend upon much the same causes which are responsible for the principal agent of cement formation. They are therefore plentiful in most beds in the marl, because they are produced at the same time and under the same conditions as the marl. Many marl beds may be seen on the other hand, which contain few if any shells. They are not broken down so that their identity is lost, as many would have us believe, for where shells exist in a bed, they may be seen at some depth, delicate and frail but perfect in outline, so that if they are the sole cause of marl their fellows should have remained in great numbers and many partly broken down, instead of here and there a perfect shell at fifteen and twenty feet below

the surface. In soundings of twenty to fifty feet beneath the surface of the water under that many feet of marl or in the center of a lake, they are nearly and often entirely absent. They could scarcely be held responsible for the presence of marl in such quantity at that depth.

§ 3. Sedimentary theory.

Among all reasoners upon the subject there is no difference of opinion as to the ultimate source of marl. It certainly came from limestone through erosion and the carrying power of water. Another basis point of this theory is also true. Marl is deposited much like a sediment. It lies very evenly unless disturbed by sudden jumps in the outline of the lake bottom. Further proof of the theory does not appear to exist. Marl deposits do not seem to occur regularly in given districts, they do not appear to extend in a given direction and so far this theory has not assisted in the location or accounted for the peculiar facts which hold good in this formation.*

§ 4. Chemical theory.

According to the theory of simple chemical precipitation of marl from spring waters, the marl should be deepest, piled or crusted about the mouths of these springs and stopping by its accumulation their outlets. Such is not the case as the marl does not confine itself to the immediate neighborhood of these springs which are in most cases surrounded by sand or muck.

According to this same theory, if the water managed to escape and mingle in the lake beyond, the marl should then deposit evenly all over the bottom of the lake as it does in depositing in a kettle or basin. This is also contrary to fact as marl is very intermittent, in its deposit, is often not deepest in the deepest portions of the lake, and does seldom form a layer continuous and even over an entire lake bottom. Another question of importance is this: Is there with the relative proportions of carbon dioxide and carbonates existing in our inland lakes to-day more than enough of the latter to exhaust the power of the water at its ordinary temperature and pressure to hold in solution the percentages of carbonates existing in these waters, or will the spring water not be able to easily hold in solution the small amount of carbonates with or without the free carbon dioxide? If the calcium carbonate is not

*It does apply to some of the fine grained calcareous clays, such as those used for white brick at various points. But in no case is the separation of calcium carbonate mud from other mud anywhere near as perfect as in the bog lime. L.

great enough to overburden the water it can be held in solution in the lake with or without the presence of the free carbon dioxide. In this case the carbon dioxide can escape from the water or remain with it, but the water can yet hold in solution its salts of calcium and magnesium and carry them out of the lake without depositing them as marl.

Two facts are to be ascertained before this theory can show the necessary conditions under which it may be possible to operate.

(1) What is the point of solubility of our spring waters, or the percentage of those salts necessary to produce over saturated solution?
(2) Is the percentage of calcium and magnesium salts in the ground water below or above the percentage? If below the theory must be groundless for it must be above in all cases supplying a cause for all phenomena in regard to the formation of marl.

(1) The point of saturation of spring waters and the influence of carbon dioxide upon the same:

After search the carefully conducted series of experiments of Treadwell and Reuter upon the solubility of carbonates was found by the State Geologist and an abstract, translated from the German by him, will be found elsewhere.

(2) We have to compare with the results of these experiments the actual proportions of calcium carbonates existing in the spring waters of lakes and springs of Michigan, as given below. (See page 46 and also the hardness tests of Cloverdale on page 131.)

According to Treadwell and Reuter's carefully made experiments, water at ordinary temperature and pressure containing no free CO_2 may yet contain permanently 0.38509 grams of calcium bicarbonate or .238 CaCO_3 per liter, while the authorities quoted below estimate it at differing temperatures and pressures from .7003 to 3. per liter. Now the analyses of waters from Michigan show a content of calcium carbonate from .175 to .250 grams per liter or 175 to 250 parts in a million. With this in mind it can easily be

ANALYSES OF JARS OF WATER FROM CLOVERDALE DISTRICT BY A. N. CLARK
FOR STATE GEOLOGIST AT MICHIGAN AGRICULTURAL COLLEGE LAB-
ORATORY. INTENDED TO BE TIGHTLY SEALED AND PROMPTLY
ANALYZED BUT NOT THOROUGHLY SATISFACTORY,
CO₂ NOT ENTIRELY RELIABLE. RESULTS
STATED IN PARTS IN 1,000,000.

Number of Sample.	Location.	Carbon Dioxide.	Calcium Carbonate.	Magnesium Carbonate.
1.....	Boiling spring at the head of Long Lake.....	0.00	100.00	67.80
2.....	Water at outlet of Long Lake, running creek.....	44.00	217.00	100.00
3.....	Well in vicinity.....	3.30	160.00	69.7
4.....	Large boiling spring near sounding, No. 41.....	19.8	200.00	75.3
5.....	Horseshoe Lake, between sounding 39 and 40, in 50 feet of water.....	19.8	117.00	85.6
6.....	From bottom of marl basin in 10 feet of water, sounding 45.....	6.	100.00	75.6
7.....	Surface of basin. Marl 6 inches beneath water surface.....	.....	70.	58.
8.....	Spring at side of Horseshoe Lake (N. lobe, not sounded).....	15.4	160.	81.7
9.....	Spring at head of Guernsey Lake, surrounded by gravel.....	66.	130.	61.3
10.....	Surface water at Guernsey Lake.....	0.	40.	71.1
11.....	Water at bottom of Mud Lake (35 feet) with 18 parts per million dissolved Fe ₂ O ₃ & Al ₂ O ₃	6.6	53.6	trace
12.....	Water from surface of Mud Lake.....	0.	30.	trace.
13.....	Seepage spring on Mud Lake.....	0.	80.	62.
14.....	Water from well on divide between Long and Mud Lakes, 35 feet. Quicksand at 18 feet, with 12 parts dissolved, Fe ₂ O ₃ & Al ₂ O ₃	60.	80.	28.
15.....	Water from drive well 25 feet into spring, which formerly emptied into Long Lake, between Long and Mud Lakes; with 24 parts dissolved Fe ₂ O ₃ & Al ₂ O ₃	39.6	240.	116.
16.....	Stagnant water in ditch which formerly connected Mud Lake and Long Lake. Metallic scum and red bottom; with 16 parts dissolved Fe ₂ O ₃ & Al ₂ O ₃	44.	48.	16.6
17.....	Water from well on high divide between Long and Twenty-One Lakes; with 50 parts of Fe ₂ O ₃ & Al ₂ O ₃	39.6	156.	203.4
18.....	Spring above level of Pine Lake.....	22.	170.	80.2
19.....	Outlet from Pine Lake, Pine Creek.....	6.6	80.	76.6
20.....	Large boiling spring near outlet of Pine Lake.....	11.	138.	81.7
21.....	In 25 feet of water, center of Pine Lake.....	6.7 4.4	80. 57.	69.6 75.

WATER OF OTHER REGIONS ANALYZED FOR CARBONATES.*

No.	Location.	Free CO ₂ .	CaCO ₃ MgCO ₃ .
1	Fremont flowing well.....	0	100
2	Water, spring in marl bottoms, Corrinne.....	28.40	210
3	Water at Straits of Mackinac.....	0	120
4	Traverse Bay at Traverse City.....	0	150
5	Duck Lake near Green Lake. Spring at head of lake.....	.....	Marl
6	Outlet of Duck Lake. Sandy bottom.....	0	165
7	Water south end of Central Lake.....	24.2	200
8	Clear water of Mound Spring near Central Lake.....	0	190
9	Water in spring 100 feet above Central Lake.....	0	190
10	Flowing well in East Jordan.....	0	210
11	Kettle near Manistee Junction, is 15 or 20 feet lower than Round Lake near by; it is supposed to discharge by an underground channel in the Pere Marquette River.....	0	110
12	Long Lake, Manistee Junction, red water.....	0	205
13	Water, Round Lake, Manistee Junction.....	0	185
14	Outlet of Long and Round Lakes, Manistee Junction.....	6.60	175

* The content of CO₂ here given cannot be relied on as the bottles were stoppered with cork, permitting the escape of the gas. Analyzed by A. N. Clark at the M. A. C. Laboratory.

seen that the carbonated waters of our springs and marl lakes are generally far below the point of precipitation. The water of these springs and lakes could take into solution 100 or more parts in a million of calcium carbonate instead of being over burdened and precipitating them in marl.* It appears very clearly that Treadwell and Reuter's experiments are carried on under artificially produced conditions which tally closely with those found in our springs and lakes. They have decided for us carefully the precipitating point at which carbonated waters with various pressures of free CO_2 , and temperatures usually 59°F . cease to bear in solution carbonates in the form of the bicarbonate. They find that point above that of Michigan spring waters, or in other words show very clearly that our spring water can generally take more salts into solution instead of being ready with slight changes of temperature and pressure to precipitate those which they already carry. In other words our spring waters cannot precipitate their bicarbonate as marl by the simple chemical process of precipitation from a saturated solution, because they lack considerable of being saturated.

§ 5. Indications by circumstances of occurrence.

In discussing the origin of marl to form as perfect a chain of evidence as possible the conditions obtaining must be determined as accurately as possible.

If analogies are used as proofs the conditions in both analogies must be alike. If this is not followed fatal mistakes are likely to occur.

An agent has produced an effect which is before us in the form of marl beds. The bearing of the facts concerning position, composition, variation in composition, location, variation in depth, foundation or basis and covering, which we have described, should be studied with this in mind: The marl beds lie upon the surface or in the present geologic stratum, and since they are not covered by any great thickness of earth and are clearly produced since the

*Compare also the analyses in U. S. G. S., Water Supply Paper No. 31.

glacial period from the fact that they lie in the hollows left by the glaciers, the agencies producing them must be modern as well.

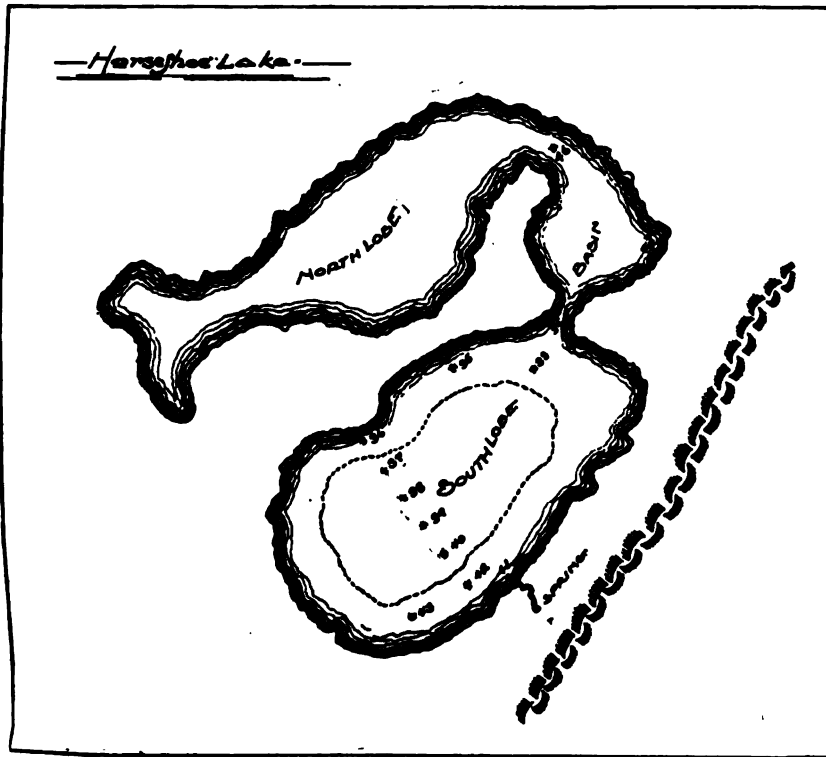
Marl has been described elsewhere as a complex compound. In the impure marl there are large percentages of insoluble matter which can readily be traced to the presence of foreign clay, sand and organic matter. It can be readily seen that these have nothing to do with the production of marl and therefore the very purest samples of marl must be considered in order to arrive at a conclusion in regard to its origin. As marl is analyzed in the laboratory it consists of calcium carbonate, forming nearly the entire percentage, magnesium carbonate (always in very small percentages, that is, in the very pure sample), iron and alumina, organic matter and traces of sulphuric acid and sometimes phosphates.

The following is the analysis of such marl:

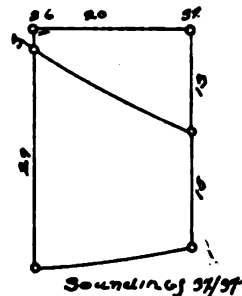
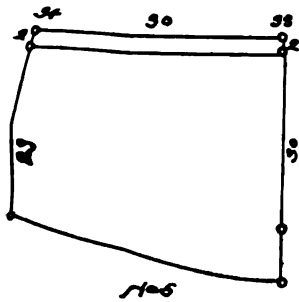
Calcium carbonate	95.231
Magnesium carbonate .....	.946
Ferric oxide .....	.536
Alumina .....	.159
Silica insoluble	1.205
Silica soluble	1.316
Organic matter	1.510
Water .....	.300
Phosphoric acid	traces.
Sulphuric acid	slight traces.
Chlorine	slight traces.
Alkalies	traces.
Total	101.203

Very likely such a marl as the foregoing is as nearly as possible to purity as can be obtained. The content of organic matter is too low to be typical, while the content of soluble and insoluble silicates is a trifle high.

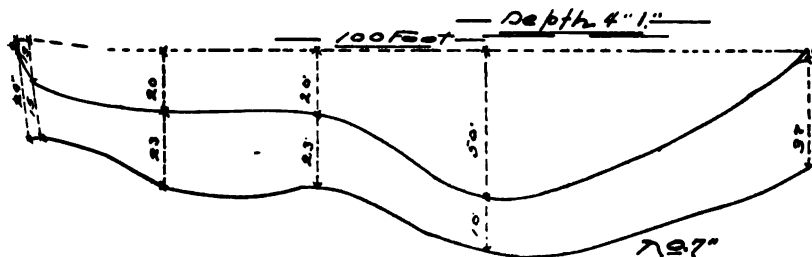
There is always the marked difference in percentage between magnesium and calcium carbonates above, excepting when a clay forms a part of the deposit, when the percentage of magnesium carbonate may increase to large percentages. In very pure marls or in those containing 90% and over of calcium carbonate, the magnesia does not form any large proportion. It is noticeable that in the study of deposits for factory purposes, it is found that where other impurities increase the magnesia increases as well. The only direct source of carbonates about to be studied is the water which in all cases lies or has at one time lain above the



SKETCH MAP OF HORSESHOE LAKE, CLOVERDALE, T. 2 N., R. 9 W.



No. 6.



HORSESHOE LAKE, CLOVERDALE DISTRICT, T. 2 N., R. 9 WEST, WITH DIAGRAMS OF SOUNDINGS.

deposit. Now if all the salts contained in the hard water were precipitated, the proportions between the calcium and magnesium in the water should be the same as the proportion of calcium and magnesium in the marl. Such is not at all the case. Notice in the foregoing analyses of waters from springs and lakes about Cloverdale (pp. 20 and 21), that the proportion of calcium carbonate to magnesium carbonate is about 2 : 1. No analysis of marl was ever seen in which the proportion was anywhere nearly equal,* the proportion of 90 : 3 being the most typical. This brings to light a very important principle or lack of principle ruling the formation of marl and as it occurs with other compounds besides magnesia it will be well to notice it in the outset, to wit, the lack of the relationship as established between the compounds in the water and the compounds in the marl. This is most easily illustrated by the wide distance between percentages of calcium carbonate and magnesium carbonate in the marl deposit. As found in water CaCO_3 : MgCO_3 :: 2 : 1, but in marl :: 90 : 3. In relationship of iron and alumina it cannot be shown as well that they differ because in both marl and water they are found in much smaller amounts. They are always very low in the purest marls. Especial search has been made for bog iron in the presence of marls. Here we meet a very interesting fact; marl does not occur in admixture or in the immediate presence of bog iron ore. One locality was noticed where a marl lake was drained by a creek that had bog iron ore along its course, but no bog iron could be found in, or immediately surrounding the marl. There is only one case in which the iron may increase to any appreciable extent. This is in deep water soundings where the marl has been displaced by a mucky marl. Such was the case in the following sample of muck-marl found in 54 feet of water at center of Horseshoe Lake, Cloverdale region:

	per cent.
Insoluble	15.14%
Fe_2O_3 (Al_2O_3)	13.73
CaCO_3	43.13
MgCO_3	1.66
Organic matter	26.34

The surprising features of this analysis are the high per cent of iron and aluminum oxides and organic matter.

*This may perhaps be accounted for upon the chemical theory by greater solubility of magnesium salts, for we have as yet no exact data as to the relative solubility of the calcium and magnesium carbonates, and yet it is not likely that so great a difference would exist. L.

The chemical agency in the deposit of iron oxide must therefore be different in the case of springs from that working in the marl beds into which these same springs empty. For example, an intensely hard water spring is seen to empty into a pure marl lake. The growth of water plants along from the spring is coated with a thick deposit of iron oxide. No marl is deposited. On the other hand, in the lake immediately below there are but traces of iron and nearly all the deposit is calcium carbonate. This leads us to conclude that the agencies most active in the precipitation of iron and calcium are different at the spring and in the marl bed as the same water furnishes material for both. There is plenty of iron left for precipitation in the lake as the waters emptying out of the same show about the same percentage of iron.

Sulphuric and phosphoric acid are usually estimated as salts. In the purest marls they are scarcely ever far above 0.30%. In deep specimens where there are large proportions of organic matter they sometimes run higher.

The organic matter is a component part of every marl which plays a very important part in its history. As we speak now of the purest marls only, it is here found in small percentages. It can never really be said to be absent and is that compound or constituent part of the marl which is the most widely fluctuating. There are found certain exceptions (see Lime Lake, p. 133) where the marl is a nearly solid shell bed. In such a case, the conditions having been always favorable to the growth of shells, the quality remains constant even at a great depth. The ordinary marl bed varies in composition. It is very much higher in content of organic matter at the bottom than at the top. It often happens in a bed thirty feet in depth that at the top it is 95% CaCO_3 and at the bottom 65% to 80%. The change is generally due to increase in organic matter at the expense of the content of calcium carbonate. In a lake, of which the bottom is entirely covered with marl and the shallows around the shores consist of deep marl covered with but a few feet of water, the marl toward the center of the lake, as the water deepens, becomes much higher in content of organic matter and of course suffers in its percentage of calcium carbonate.

The content of magnesium carbonate does not increase with depth of the sounding, but may vary, either becoming slightly greater or less. If clay has sifted in with the marl it usually shows in a higher percentage of magnesium carbonate.

Marl beds are not seen to show any variation in the content of iron, chlorine or other such foreign substances where springs directly above such beds contain the same.

Having reviewed the extensive variation in composition and depth, together with the condition of surface and basis for deposit, the next important consideration is the water above the marl.

The water of our springs and lakes as shown by our analyses on pages 46 and 131, runs as follows:

Free CO_2 , 0 to 44 parts in a million.

CaCO_3 , 80 to 217 parts in a million.

MgCO_3 , 62 to 100 parts in a million.

This excludes the soft water lake and the well on the divide which seem to be extremes on either side.

The water so laden flows from the springs into the lakes by the springs upon high land and by the water holes or living springs which empty under water in the lake and are indicated by open water in the dead of winter and are avoided by skaters as air holes. In either case the cold water will at once flow down till it reaches the deeper parts of the lake, being naturally heavier than the somewhat heated water about it. The water of the spring holes must carry all its CO_2 with it as there is no open air for it to escape to. The running water of the upland springs must lose some of its CO_2 , but not all as it is a gas, heavier than air and does not escape easily.

There has been some careful research into the behavior of lake waters,* and an instrument called the thermophone has been invented to trace accurately the changes of temperature at great depths, not easily reached by an ordinary thermometer. It was found by a study of Lake Cochituate, near Boston, that in very deep water the bottom temperature remained the same and the water stagnant throughout half the year and that in the fall and spring a general vertical circulation of the water took place. "The diatoms and some of the infusoria are most abundant in spring and fall, or during the two seasons of the year when the water circulates freely from the top to the bottom." The temperature of our lake waters controls their density and their density their power to move by the law of convection, the warmer water rising, the colder sinking.

*Warren and Whipple, *Meteorological Journal*, June, 1895. *Technology Quarterly*, July, 1895, VIII, 2, pp. 125 to 152.

The position of the water again controls its power of getting to the air and losing its carbon dioxide. It will be seen by careful perusal of the experiments of Messrs. Warren and Whipple that our deeper lake waters must have a systematic movement each year. In the deeper portions of 30 to 50 feet depth or more, the water remains at or near the point of 39.2° F. or that of greatest density. It is a little above that point in winter while the surface water next the ice is of course nearer freezing point. The water in the deeper portions of the lake already referred to moves in spring and fall changing places with the surface waters. It then acts as a reservoir of cold heavily laden carbonated waters which replenish the surface waters, and the carbonates and CO_2 are carried to the surface where any free CO_2 may escape. It is then clear that the very cold water of our springs may not in summer flow at once to surface of the lake and is not at once thoroughly aerated by contact with the air at the surface of the water, but on the contrary flows to the deeper parts of the lake and is buried for a season till convection brings it to the surface when it naturally spreads out, being the warmer, and has free access to the air.

Now we find that to no great extent is the marl precipitated in deep water. In soundings made in 40 and 50 feet of water, the marl nearly lost its nature, becoming marly muck. When we allow a basin with spring water to stand, the CO_2 collects in bubbles on the bottom and sides and little rises to the surface. In the same way we can tell that it collects on the bottom of a lake, for if we stir the bottom small bubbles of gas find their way to the surface. This is the condition in which the water remains as it lies deep in mid lake.

It is difficult to tell from a comparison of the analyses of lake waters and those of the springs that flow into them whether any carbonates and CO_2 are lost by precipitation from the fact that the lake waters must of necessity be diluted by surface drainage waters and rain water containing no carbonates. It will therefore be necessary to compare the springs with each other, the wells with each other, and the lakes, taking each sounding that corresponds in position with the other. The Cloverdale Lakes may be graded in the intensity of their deposit, the first named having the deepest marl and most active deposition, the last having but traces, in the following order: Horseshoe, Long, Price, Guernsey, Mud Lakes. Upon comparing Nos. 1, 8, 9, 13, 18, 20, which are samples

of spring water, analyses of which are given on page 46, it will be found that the most intensely marly lakes have the springs with the greatest content of carbonates and grade down to the soft water lake, which in turn has a spring with the smallest content of carbonates. Upon comparison of well samples 3, 14, 35, 16, 17, the same rule applies, but not with equal clearness as the well near Mud Lake was scarcely more than a surface well.

Nos. 7, 10 and 12 are the surface samples of Horseshoe, Guernsey, and Mud lakes. They again show the same order of the marl deposit. They all lack free CO_2 and contain carbonates in the order of the marl deposit. Horseshoe is the greatest and Mud Lake is again least.

Nos. 5, 11, 21 form a comparative set of the deep waters of Horseshoe, Mud and Pine lakes. The relation is again maintained without break although the free CO_2 in Mud and Guernsey are nearly the same.

For comparison of water in the lake itself we have Nos. 5, 6, 7, of Horseshoe Lake. These are named in the order of their depth, No. 5 being taken in 50 feet of water in mid lake, No. 6 in a marl basin and at the bottom next to the marl, and No. 7 at the very surface. It will be seen that according to these analyses, the water is steadily and rapidly losing its content of CO_2 and carbonates as it approaches the surface. At the bottom it had the highest (19.88 parts CO_2), at ten feet it has but 6 parts, and at the surface nothing. The carbonates are lost much in the same proportion, less of the magnesium carbonate being lost than of the calcium carbonate. This tallies very well with the marl which gains more calcium than magnesium.

The above comparisons deduced from the table of analyses would point to the following conclusions.

The deep springs furnish the hard waters for the marl lakes.

The cold water sinks to the deeper parts of the lake, which contain a supply of carbonates and CO_2 .

When this water reaches the surface by aid of convection, it loses its CO_2 entirely or in part and its proportion of carbonates suffers as well. It must be borne in mind in this consideration, that water and CO_2 must differ in volume as the temperature rises. The water as a liquid would not have a great change of volume in rising from its temperature of greatest density in mid lake to lukewarmness at the surface under a summer sun. On the other hand

carbon dioxide would be almost entirely lost and would expand greatly. While its content per liter of water at the depth of 10 feet would be much less than at the bottom of the lake, one thing is certain that at the surface it is lost entirely, not being contained in any of the samples taken from the surface of any of the lakes.

Having discussed the composition of marl itself we find it influenced by the depth of water over it and by its own depth.

Upon the study of water and its content of carbonates we find the opposite. The deep water contains the greatest amount of carbonates, but does not release them till shallow water or the surface are reached. Heat and the seasons play an important part in renovating the deep water, bringing it to the surface where it loses its carbonates by some agency.

The conditions of marl formation have been discovered as nearly as possible. It is found that the carbonated waters even if at first rendered stagnant are brought twice a year to the surface, to light and heat, but that according to carefully conducted experiments, they cannot lose their carbonates by simple precipitation of the carbonates upon withdrawal of CO_2 , because none of the compounds in question are in great enough proportion to form a saturated solution.

For a pure analogy and not as a proof, let us look at other parallel cases in nature where chemical compounds exist in such mild proportions that it does not seem possible for change to take place, but nevertheless such change is going on upon a large scale. The nitrates or compounds of nitrogen can not readily be formed and made soluble from the compounds existing in the soil and plants would suffer without them. They are formed, however, by the interposition of an outside agent. This is a minute living organism that forms upon the roots of the plant at the same time, forming a large amount of soluble nitrates for the use of the plant. This is a case of chemical recombination impossible without the aid of this living organism. The process of biochemical down-tearing is so varied and frequent that it need hardly be pointed out. The process of rotting so necessary to the destruction of plant and animal life and its recombination in simpler forms fit for plant food, is accomplished by millions of bacteria. Acids, alkalies and numbers of new compounds are formed where if chemical action alone were depended upon, plant life would starve in need of less complex food.

It is here in the discussion of precipitation of calcium carbonate in the form of marl, that a new set of phenomena or conditions must be duly represented and described.

There are clearly live marl lakes, i. e., lakes that are depositing at the present time. The deposit is carried on in shallows in intensely marly lakes. It is not confined to plant organisms that can be seen with the naked eye. The reason for this is clearly proven. All live and dead plants or all inanimate objects on the bottom are covered with the white deposit of calcium carbonate. The objects covered need not necessarily have grown in the water. Many trees may dip half decayed branches into the water, yet these twigs are covered with a thick coating of the marly substance. The numerous water plants upon the bottom in the shallows are also thickly coated with white. One plant especially thrives in these shallows. It is to be easily distinguished by its whorls or leaves at each joint.* It would seem probable that these plants, especially in shallow water would act as distributors for their coating of marl, as the ice of winter must certainly tear them out, in being floated to different parts of the lake as the ice breaks up in the spring.

The marl in the shallows of such a lake forms around everything, forming pebbles around rushes and roots that extend above the surface of the bed. The pebbles are somewhat hard and in boring they sometimes seem like stones. The roots die away leaving a hollow nearly enclosed pebble. The marl in these cases forms fine accretions and is very granular, seeming at first exactly like sand, but yielding to repeated efforts to crush it with the finger. Upon closer examination of plants upon which the marl is depositing it is found that they are coated with a fine slime which is more or less whitened by the presence of the particles of marl. When a lake or portion of the same lake is examined where the deposit is not so active, the same slime is found, but it is not so thick and it is transparent rather than white, on account of the absence of the white particles of marl. Such was the case in a chain of lakes near Colon, the difference between the lower and the upper of the lakes being very marked in this respect. The active precipitation of marl in this manner was first remarked in notes on Horseshoe Lake near Cloverdale. It is an interesting fact that, while the shores of this lake were thickly encrusted with thick marl in the

*This is the Chara referred to by Davis, Chapter V. L.

process of precipitation, the marl at the center was of the poorest, though not over a few hundred feet removed. Several actively depositing lakes have been noted since. Such a lake was usually the upper lake of a chain. It received little drainage water and had the first of the spring water. The precipitation, while it is taking place must be very rapid. Stakes stuck in the marl as anchors for fishermen are whitened by the deposit of marl; branches, twigs, etc., sometimes have an incrustation of a quarter of an inch or more in thickness. Even in such lakes the marl when traced out into deep water, becomes darker and heavier in organic matter, and if sounded to the bottom, shows much the same increase in organic matter. It appears the only feasible and true explanation of the origin or exact method of precipitation of marl that minute water organisms absorb the CO_2 from the water in building up their life and leave the calcium carbonate to precipitate upon the twigs, plants, or bottom, or anything available. That the visible water plants serve mainly to precipitate the marl I can hardly believe as it clings to the dead twig as thickly as to the live. Moreover it fastens to wood that has not had life while in the water and could not have evolved carbon dioxide.

There is every reason, however, to believe that these plants aid in increasing the content of calcium carbonate in the marl deposits even in the deepest water. In 50 feet of water at the center of Horseshoe Lake, a long trailing vine was brought up from the bottom, these vines often winding about the augur. The vine had the distinct and very strong odor of pole cat. It was without doubt some one species of the Characeæ. The family are well known for their high content of calcium salts.

The *Chara foetida* as analyzed by Gustav Bischof is as follows:

	per cent.
Ash of dried plant	54.84
Of this ash calcium oxide	54.73
Carbon dioxide	42.60

Such a plant dying would add a considerable portion of its substance to the formation of a marl bed.

It is not difficult to believe that the Characeæ are responsible for the growth of the marl bed when the actively depositing marl beds are seen to be covered thickly with a luxuriant growth of this plant. As they have stems and finest branches thickly coated with

the calcium carbonate also, every crop each year forms an addition to the bulk of the marl bed. This luxuriant growth is often in water so shallow that in winter the ice must freeze down nearly to the bottom, enclosing the plants, stem and branch. In the spring when the ice loosens and is shifted into deeper water by the winds, a large number of these plants must be carried and deposited in mid lake. This will account in part for the distribution of marl in deep water. It is hardly deemed possible, however, that Characeæ are the sole cause of the growth of our vast beds of marl, for the following reasons:

Actively depositing marl is found in the absence of these plants. In the absence of these plants the marl encrusts all objects around, dead or alive. Fully as thick an incrustation has been found upon dead twigs and old stubs stuck up in water by fishermen, in a lake nearly devoid of Characeæ, as in those the bottoms of which are covered with plants. Another very significant fact is that in cases where the plants themselves are taken from the water, they are found surrounded by a gelatinous scum. Where the marl is not depositing thickly this scum is nearly transparent, while on thickly depositing beds its surface is whitened by the presence of the particles of calcium carbonate.

We must notice in connection with this another important fact. Where the marl is depositing upon a bare bottom, upon rocks and pebbles as noticed at Long Lake, Cloverdale, the accretions as deposited, have a pronounced inner lining of chlorophyl.* This green color does not show upon the outside of the incrustation which shows the white or gray color of marl. Such a deposit is very soft and breaks apart easily when in the water. When, however, it is exposed to the air for some time it hardens so that it is difficult to tear apart. The pebbly concretions formed in some lakes are rather hard and gritty even under water and were even found in two cases at the depth of 6 to 10 feet in the marl bed, feeling like pebbles when struck in boring, yet the beds were almost entirely free from silica in any form. Free sand was entirely absent. The very hard pebble like accretions seen in both instances were on the south side of the lake in question.

It seems possible that other forms of plant life, invisible to the naked eye, also assist in the precipitation of the salts from the

*Showing the presence of the blue green algae, referred to in Davis' paper. I have noticed in Higgins Lake, the sand of the bottom continuously cemented in a thin layer about 1-10 of an inch thick, brown above and green below. L.

water. While the Characeæ in shallow water are coated thickly with marl, in deep water there is no sign of the scummy or gelatinous covering, nor is the marl of anywhere near as limy a composition, showing that the precipitation process is largely if not entirely inoperative in deep water. Yet in water 20 to 25 feet deep there is often if not always a fair marl. Sample No. 4 (sounding 10) at the center of Long Lake, Cloverdale, shows at the bottom of a 20 foot marl bed in 25 feet of water, 69.30% calcium carbonate and 11.91% organic matter.

There is another very remarkable feature about very intensely hard water lakes. The waters are often as clear as crystal. Every dark particle of organic matter not only settles to the bottom, but is covered as well with the marly precipitate. The plants and debris of mid lake are buried by the marl as well as those nearer the shallows, but the deposit of marl must be much more rapid in the latter because of the greater content of calcium over organic matter which it always contains.

There can be little doubt that purely chemical precipitation of marl from our dilute spring and lake waters would be impossible. The analyses of the Characeæ and their presence in such large numbers proves them to be surely responsible for a part of the composition of the marl bed, especially in deep water. For in deep water the organic content is always very high and the forms of the water plants can always be distinctly traced, embedded and preserved in the impure marl. The analyses always show a great proportion of organic matter in deep water marl, or in most marls taken at great depths, whether in deep water or at the bottom of a deep bed or both. On the other hand a local precipitation takes place and that very actively. Moreover it takes place at or near the surface and very little in deep water. That was well shown by samples 5, 6 and 7 of the waters at Horseshoe Lake, Cloverdale district. These were in their order, analyses of water at 50 feet in mid lake, water on bottom at 10 feet in depth, and water at the very surface. From deep water to the surface the CO_2 escapes entirely and the carbonates are least at the surface also.

The manner in which the marl is laid down also favors a precipitation process. Where the regularity of the bottom will allow it the marl is deposited so evenly that it is sometimes impossible to note any such variation in depth, the marl remaining very even over an extended area and then increasing or decreasing gradually.

Of course in many cases, our lake bottoms being full of sudden jogs, the marl must vary also. As a rule it behaves much like an even deposit or sheet, leveling hollows and decreasing the abruptness of sudden rises in the original bottom. See for measurements taken, Cloverdale, Central Lake, Rice Lake.

Another point of significance is that near the surface, there are many samples of marl taken which have a content of 95% calcium carbonate and sometimes but a fractional per cent of organic matter, the latter indicating the proportion of plant tissue used in building up such a portion of the deposit. According to such analyses (see commercial analyses of marl in the appendix) the plant life remaining as organic matter would not be sufficient to account for the production of such very pure marl, being sometimes but a fraction of a per cent.

The following would then appear as the most plausible explanation of the manner of precipitation of marl.

The mineral is washed from the soil and finds its way to our deep underground springs as a bicarbonated salt.

These springs issue from the deep cuts and clefts left by the glaciers and called by us lake valleys.

Analyses of the water and parallel experiment prove that the solution of carbonates and free carbon dioxide are in too small quantity to form a saturated solution and therefore cannot from purely chemical laws precipitate as marl on the bottom of the lakes.

The very dense cold waters of the springs, whether they issue from bottom or sides of the lake, seek by their greater weight the deeper portions of the lake. They remain there with their burden of salts and CO_2 till the semi-annual overturning of the still water, when they approach the surface. When the water reaches the surface, it is warmed by the direct rays of the sun. If the place is sheltered and the water is shallow, the bottom reflects the rays of the sun still further heating it. If in deeper water not all the rays of the sun are stopped as they are wasted in heating a greater depth of water to a less temperature. The warmer the water the better all plant life thrives in it. These plants are of two kinds, the larger fixed plants that may be seen without the aid of microscope and those invisible to the naked eye.

The former or larger fixed plants live on the bottom and absorb a large percentage of the carbonates in their growth and also give

off free oxygen. The smaller plants are movable, being carried slowly through those portions of the water where they have sufficient sunlight and warmth to multiply rapidly. They must also give forth oxygen in large quantities, but as they must live toward the surface or warmer part of the water and be capable of reaching every particle of it, they form a more perfect oxygen carrier and serve to furnish oxygen in a very thorough manner for precipitation of the salts from their weak solution. They could thrive only at or near the surface in deep water on account of the lack of heat and while supplying an even distribution of oxygen, would not thoroughly do so as in shallow water.

The result of this is that in very shallow water the precipitating process is rapid wherever sunlight and warmth have made the very best conditions possible for the growth of plant life. Here the rate of formation of marl is more rapid and while plant remains are always found, the proportion of precipitated salts is greater than that remaining from the breaking down of gross plant tissue. The method of precipitation is a process of accretion. That is to say, every particle of organic matter, silt, etc., that finds its way into these waters where the process of marl making is very rapid, is surrounded by a coating of marl and sinks to the bottom, forming forever a portion of the deposit. The Characeæ and larger water plants containing lime in their formation are torn from their places by ice in winter, or perhaps to some degree by the action of the wind and disintegrate in the deeper parts of the lake, helping to form the deposit. The plants which themselves form in deep water are not encrusted to any extent with the marl and then when they disintegrate do not make as marly a formation. Moreover the dead drift of silt and other matter which must always fall into a lake is not in mid lake coated as thickly as in shallow water where the process is much more rapid. These particles sink to the bottom of the lake and form a part of the bed as they do in the shallows, but on account of the lack of precipitation upon them they add a higher amount of organic matter to the growing bed. As the water in turn throughout a depth of 50 feet is none of it heated so warm as on shallows where nearly all the heat is reflected from the bottom, the finer more minute water plants do not multiply so fast or furnish as much oxygen. Where the heat is greatest at the surface they must, however, cause a deposit to some extent. It follows from these conditions that the marl must

form more slowly in deep water and that its organic content must be greater.* As many of our lakes are filled with marl varying from twenty feet in mid lake to thirty or forty feet in depth on shallows or points near shore, or in marshes at that depth at the center, the following must have once been the condition:

Our lakes were originally thirty or forty feet deeper when their basins contained no marl. The marl first deposited was deposited in much deeper water than this as the water level of our lakes has sunk greatly in the last few years. All the soundings made in deep water or to the bottom of deep deposits show them to be, one and all, of a more impure character than those in our shallows at the surface. The only exception found was a nearly pure shell deposit which at surface contained 90% calcium carbonate and at a depth of 17 feet 92%. See Nos. 6 and 7, page 83.

So universally does this rule apply that in one case a sudden change of former water level could be traced by a like sudden variation in the quality of the marl overlying the bottom. A broad glacial chain of dried lake beds extended from east to west. There were lakes above which emptied through a narrow stream which flowed over a bed. A line of soundings from north to south at right angles to the length of the system showed an extensive shallow which originally lay on the north side. At about the center of the depression was the deep channel of the former body of water. Then at the south side was another area of shallows. Nearly all was dry land excepting the small stream named. Instead of the valley being filled nearly even with the deposit of marl and enclosing marsh growth, the deep channel was marked upon the surface as a sharp depression. The shallows were of finest marl ever seen, being nearly pure calcium carbonate with but a trace of organic matter and other salts. It formed a shallow deposit some six or seven feet in depth. The channel was very impure and formed a rather sharp line of contrast with the pure shoal marl, following the rule above mentioned regarding the quality of marl as accounted for by depth of water over it.

The whole basin was once covered with water, the area of pure marl consisting of a terrace of shallows on either side. This deposited pure marl in shallow water till it reached the surface and marsh growth sealed the deposit on the shallows, stopping its growth. The marl in deep water formed in a much more impure

*See paper by Wesenberg-Lund, p. 68.

state on account of the greater depth of water over it. It would have filled to the surface, becoming purer with shallower water if the drainage had not in some way altered so that the water level sunk to the surface or near the surface of the marl and organic matter in the shape of marsh growth choked and sealed the deposit. This peculiar suddenness of change in quality and formation was traced for a half mile to the first chain of upper lakes. The channel broadened in places, but its surface never showed other than a silt formation, the marsh at the present time being in process of sealing the deposit. The upper lake of the chain, however, while it showed a gradual decrease in quality with increase of depth was actively depositing in the shallows at the upper end.

We would conclude that in former times the process of marl formation was much slower on account of the greater depth of water and that our fall of water level of late years has hastened the process, bringing deeper water nearer the surface and heat and sunlight. We also conclude that the great clearness of our lakes is due to the fact that every particle of floating silt and dust and matter no matter how large or small, is surrounded by the fast depositing marl and buried in the deposit. It is noticeable that many lakes where the process has ceased and the marl is being covered with silt, show a very dirty reddish water due to particles of deteriorating organic matter. Yet these lakes are fed by springs and have outlets.

It is difficult always to account for the presence of marl in one lake and its absence in another. In most cases there is found a difference in water supply. Mud Lake and Long Lake, Cloverdale district, were one soft water, and the other hard. The former was fed by surface soft water springs and the latter by deep water springs. The wells near each showed the same difference in hardness of water. In portions of the State where there are no hard water springs no marl is found. Such were said to be the conditions surrounding the limestone district about Escanaba. A prospector who had explored carefully said that there were no marl lakes within thirty miles. The hard water was tapped only by the deepest artesian wells. It was noticed where two lakes were near enough together to be compared that the one indenting the general outline of the country deepest and tapping the most hard water springs, contained the deepest deposit.

There is yet another circumstance which must be accounted for. This is the presence in one part of the lake of a marl deposit which may taper off to a sandy or clay bottom not covering the whole lake bed. In the first place it will be noticed that in a lake not covered entirely with marl, it favors with its presence the bayous, points, and shallow water and in most instances, though not always, avoids deep water. As light and heat are always necessities of plant life the facts of the location of the deposit in shallow water in the presence of the same is very good argument for the theory of vegetable origin. But there is still a further fact to account for. Even in shallows a bed may end or taper to the original bottom, generally becoming toward the edges much more highly organic in its nature. This is illustrated by the fact that sometimes at one end of a lake, generally though not always the upper end, the marl is bare or has not ceased depositing and at the lower end becomes a deposit of lake silt, or in another case the marl is bare of silt at one end, though covered with water and is at the other end covered by a few inches to a few feet of silt. In other words the marl has changed its position for depositing or has continued to deposit at one end and has ceased entirely for some time to deposit at the other end and the deposit there is sealed to some depth with silt, over which there lies several feet of water. A good illustration of this was seen at Central Lake. The depth at both ends to the original bottom was nearly the same. The quality of the marl was about the same for the same depth, but the marl had ceased depositing at one end and had continued actively at the other. We must conclude from this that the conditions for successful growth of the marl producing plants of our lakes change in different parts of the lake, causing a more or less permanent cessation of the process of marl making. At Portage Lake, Onekama, this process seems to have been interrupted at intervals and continued again according to the layers of marl and organic marsh growth alternating. However, as this was the only instance seen of the kind, it would not be safe to assume from the instance of one lake, that such was the rule.

It can scarcely be argued that marl is the result entirely of the breaking down of the structure of gross plant growth for the same reason that shells cannot be said to account for the formation of all marl. At a depth of thirty-five feet stems and branches of

small size may be well defined in samples taken as can the forms of small shells. Wood of a more fibrile texture is preserved in a nearly fresh state and the grain can be clearly separated. It can hardly be said that different parts of the same plant have deteriorated at such a different rate as to leave in one portion a nearly perfect branch or shell and right beside it a marl formation that cannot be found to resemble plant tissue or anything else excepting an amorphous form of mineral. The lack of any finely preserved lime formation of the tests of minute animals or the forms of fresh water plants,* also discourages the idea that the bodies of the same have died and formed the deposit. The clearest explanation would therefore seem to be that of a chemical precipitate brought about by plant life both great and small, abstracting CO_2 , and acting where conditions for its existence are most favorable.

One of the strongest of reasons why the purely chemical theory is not true is lack of marl in some shallows and its presence in others. The lime bearing water must be distributed evenly to all shallows and should precipitate upon all at an equal depth. This is often contrary to fact, while on the other hand it would be possible for a local precipitation to be brought about in the presence and only in the presence of water plants producing oxygen.

As these views of the subject are nearly if not exactly† the same as those of Prof. Davis, given in another portion of this work, it has not been thought necessary to repeat his chain of evidence or any of his ideas except to bring out those points in the constitution and location of marl beds which would seem to prove the same idea from different facts of observation.

*But see Davis' observations, pp. 74 to 80. L.

†The main difference between Mr. Hale and Prof. Davis is that the former is more inclined to look to microscopic plants and to the abstraction of CO_2 by plant life generally as inducing a chemical precipitation favored by light and heat. L.

CHAPTER V.

A CONTRIBUTION TO THE NATURAL HISTORY OF MARL.

BY C. A. DAVIS.

§ 1. Historical introduction.

Botanists have long been familiar with the fact that, in some regions, aquatic plants of all, or nearly all, types are covered with a more or less copious coating of mineral matter, while in other localities the same types of plant life are free from any trace of such covering. In New England, for example, plants growing in the water are generally without such coating, while in Michigan and adjoining states it is generally present. In many lakes and streams the mineral deposit on the stems and leaves of the higher plants is very noticeable, and nearly all vegetation growing in the water is manifestly an agent of precipitation of mineral matter.

Various writers in Europe* and America† have called attention to the influence of the low types of plants growing in and around hot springs and mineral springs, on the formation of silicious sinter, calcareous tufa, and other characteristic deposits of such springs, and the connection between the beds of calcareous tufa which are sometimes formed about ordinary seepage springs whose waters carry considerable calcareous matter in solution and certain species of moss has been suggested, but so far as the writer knows, no one has given attention to the possible relation of vegetation to the more or less extensive beds of the so called marl, found about, and in, many of the small lakes in Michigan and the adjacent states. As has been pointed out elsewhere, this "marl," more properly lake lime, is made up principally of nearly pure calcium carbonate, "carbonate of lime," with greater or less admixture of impurities. When dry and pure it is white or slightly cream colored, nodular, coarsely granular to finely powdery, very loosely

*Cohn: Die Algen des Karlsbader Sprudels, mit Rücksicht auf die Bildung des Sprudel Sinters: Abhandl. der Schles. Gesell., pt. 2, Nat. 1862, p. 35.

†Weed: Formation of Travertine and Silicious Sinter by the Vegetation of Hot Springs. U. S. Geol. Surv., IX, Ann. Rept., p. 619, 1889.

coherent and effervescing freely in acids. On dissolving it, particles of vegetable and other organic and insoluble matter are found scattered through the solution.

§ 2. Ultimate sources.

The ultimate source of this material, except the vegetable matter, is, undoubtedly, the clays of glacial deposits and like disintegrated rock masses. These clays are rich in finely divided limestone and in the softer rock-forming minerals, some of which contain calcium compounds. Percolating water, containing dissolved carbon dioxide, the so called carbonic acid gas, readily dissolves the calcium and other metallic salts up to a certain limit. The water with the dissolved matter in it runs along underground until an outlet is reached and issues in the form of a spring. This, in turn, uniting with other springs forms a stream which runs into a lake, carrying along with it the greater part of its mineral load. If the amount of carbon dioxide contained in the water is considerable, some of it will escape on reaching the surface, because of decrease of pressure, and with its escape, if the saturation point for the dissolved mineral matter has been reached, a part of this matter must be dropped in the form of a fine powder, as the water runs along over the surface. Theoretically, then, some, if not a great part of the dissolved matter, should be thrown down along the courses of the streams which connect the original outlets of the water from calcareous clays and lakes where marl occurs, and we should find the marl occurring in small deposits along these streams wherever there is slack water. Moreover, we should expect the waters of these springs and streams to show more or less milkiness on standing exposed to the normal pressure of the atmosphere at usual temperatures. Actually, however, none of these phenomena have been noted and we infer that there is not a large amount of carbon dioxide, and not an approach to the saturation point for calcium bicarbonate, in the springs and streams feeding marly lakes.*

§ 3. Alternative methods of deposition.

We are then left, among others, the following alternatives, explanatory of marl formation: (1) The marl is not being formed under existing conditions, but has been formed in some previous time when conditions were not the same as now. (2) The amount of dissolved salts is so small that the saturation point is not ap-

*This point is considered more extensively later. L.

proached until after the lakes are reached and the slow evaporation added to the reduction of the amount of dissolved carbon dioxide in the water brings about deposition of the mineral salts. (3) Some other cause, or causes, than the simple release from the water of the solvent carbon dioxide must be sought.

The first of these suggestions is met by the fact that marl is found in lakes at and below the present level of the water, and that it extends in most of them to, or even beyond, the very edge of the marshes around the lakes, and over the bottom in shallow parts of living lakes, even coating pebbles and living shells. (2) The water of lakes with swift flowing and extensive outlets, such as most of our marly lakes have, is changed so rapidly that little if any concentration of a given volume of water would occur while it was in the lake, and there is no probability that any of the lakes visited by the writer have ever been without an outlet. Indeed many of them have outlets which occupy valleys which have been the channels of much larger streams than the present ones. Moreover, definite measurements which, however, are subject to further investigation, have been made, which show that the volume of water flowing out of these lakes is practically the same as that flowing into them, i. e., the loss by evaporation is too small a factor to be taken into account. Farther, recent investigations* have shown that calcium, as the bicarbonate, is soluble to the extent of 238 parts in a million, in water containing no carbon dioxide. As most of our natural waters, even from limy clays, contain no more than this amount of this salt, even when they carry considerable free carbon dioxide, and many analyses show a less amount of it, the fact becomes plain that even if the carbon dioxide were all lost there would be no precipitation from this cause. (3) Considering these objections as valid it seems fitting to examine into the possibility of the plant and animal organisms living in the waters of the lakes being the agents which bring about the reduction of the soluble calcium bicarbonate to the insoluble carbonate even in waters low in the amount of dissolved mineral matter, and containing considerable carbon dioxide.

That mollusks can do this is shown by the fact, which has frequently come under the writer's notice, that the relatively thick and heavy shells of species living in fresh water are partly dis-

*Treadwell and Reuter: Ueber die Löslichkeit der Bikarbonate des Calciums und Magnesiums. Zeitschrift für Anorganisch-Chemie, Vol. 17, p. 170. Summarized elsewhere in this report.

solved and deeply etched by the action of carbonic acid after the animals have, by their processes of selection, fixed the calcium carbonate in their tissues, precipitating it from water so strongly acid and so free from the salt that re-solution begins almost immediately. No natural water seems so free from calcium salts that some species of mollusks are not able to find enough of the necessary mineral matter to build their characteristic shells.

While some limited and rather small deposits of marl are possibly built up, or at least largely contributed to, by molluscan and other invertebrate shells,* the deposits which are proving commercially valuable in the region under consideration, do not contain recognizable shell fragments in any preponderance, although numerous nearly entire fragile shells may be readily washed or sifted from the marl. The average of quantitative determinations of the shells and shell debris in three samples of marl from widely separated localities was less than one per cent of the entire weight of the marl and of these the highest contained but a trifle over one per cent, 1.04%. The conditions under which marl are found are such that the grinding of shells into impalpable powder, or fine mud, by strong wave action is improbable, if not impossible, for exposed shores and shallow water of considerable extent are necessary to secure such grinding action, and these are not generally found in connection with marl.

We are, then, reduced to the alternative of considering the action of plants as precipitating agents for the calcium salts. It has been shown already that plants generally become incrustated with mineral matter in our marly lakes, and it is easy to demonstrate that the greater part of the material in the incrustation is calcium carbonate. It is also easy for a casual observer to see that in many cases the deposit is not a true secretion of the plants, for it is purely external, and is easily rubbed off, or jarred off from the outside of the plants in flakes, while the tissues beneath show no injury from being deprived of it, and again as has already been pointed out, the same species of plants in some sections of the country do not have any mineral matter upon them. It has also been remarked in a recent important paper,† that the amount of the incrustation varies with the depth of water in which the plants grow, i. e., the amount of light they receive,

*C. Wesenberg-Lund: Lake-Ilse, pea ore, lake-gytje, Medd. fra Danskgeol Forening U. Copenhagen, 1901, p. 146.

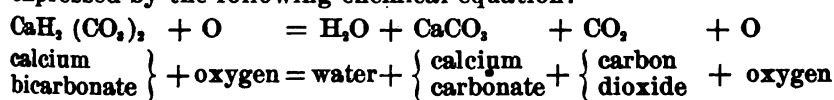
†C. Wesenberg-Lund, p. 156.

the season, and the roughness of the surface water, waves causing the incrustation to break up and fall off. The deposit is formed incidentally by chemical precipitation upon the surface of the plants, probably only upon the green parts, and in performance of usual processes of assimilation of the plant organism.

§ 4. Cause of deposition upon aquatic plants.

All green plants, whether aquatic or terrestrial, take in the gas, carbon dioxide, through their leaves and stems, and build the carbon atoms and part of the oxygen atoms of which the gas is composed into the new compounds of their own tissues, in the process releasing the remainder of the oxygen atoms. Admitting these facts, which are easily demonstrated by any student of plant physiology, we have two possible general causes for the formation of the incrustation upon all aquatic plants.

If the calcium and other salts are in excess in the water, and are held in solution by free carbon dioxide, then the more or less complete abstraction of the gas from the water in direct contact with plants causes precipitation of the salts upon the parts abstracting the gas, namely, stems and leaves. But in water containing amounts of the salts, especially of the calcium bicarbonate, so small that they would not be precipitated if there were no free carbon dioxide present in the water at all, the precipitation may be considered a purely chemical problem, a solution of which may be looked for in the action upon the bicarbonates, of the oxygen set free by the plants. Of these, calcium bicarbonate is the most abundant, and the reaction upon it may be taken as typical and expressed by the following chemical equation:



in which the calcium bicarbonate is converted into the normal carbonate* by the oxygen liberated by the plants, and both carbon dioxide and oxygen set free, the free oxygen possibly acting still farther to precipitate calcium monocarbonate.

It is probable that the plants actually do precipitate calcium carbonate, both by abstracting carbon dioxide from the water and freeing oxygen, which in turn acts, while in the nascent state, upon the calcium salt and precipitates it, but in water containing relatively small amounts of calcium bicarbonate the latter would seem

*Which is only very slightly soluble, 100 parts to the million.

to be the probable method. In all likelihood these methods for accounting for the precipitation of calcium carbonate will sufficiently explain the ordinary thin and relatively insignificant incrustation which is found on the higher plants, but for the algæ it is doubtful, or even improbable that they account for all the facts, as will be shown further on.

The calcium salt is deposited in minute crystals, and by the aggregation of these crystals the incrustation is formed on the plants. The crystals are distinguishable as such only for a short time on the newer growth of plants, but the incrustations are said to show a recognizable and characteristic crystalline structure when examined in thin section under a compound microscope with polarized light.

§ 5. Relative importance of Châra (Stonewort).

Not all aquatic plants in the same lake seem equally active in the precipitation of mineral matter. Not even all species of the same genera, although growing side by side, will be coated equally, a fact which seems to indicate some selective metabolic processes not understood. Considering the precipitation of calcium carbonate by plants as established, even if the exact physiological and chemical processes by which this precipitation is brought about, are not yet worked out fully, it is still necessary to consider the constancy of the action and the sufficiency of the agency to produce the extensive deposits of marl which are known.

If one confines his studies simply to the seed-producing plants and other large vegetable forms which are conspicuous in lakes during the summer season, while he will find them covered with a thin coating of manifestly calcareous matter, he will at once be convinced that such work as these plants are doing is but a small factor in the total sedimentation of the lake. On the other hand, if a visit be made to a lake in early spring or late fall, all plants of the higher types will not be found, so that it becomes apparent that this agency is merely a seasonal one and works intermittently. Farther study of the plants of the same body of water, however, shows that the algæ, the less conspicuous and entirely submerged plant organisms must be taken into account before we finally abandon plants as the agents of precipitation. Of these, two groups, differing widely in structure, habits and method of precipitation, will be found. The first and most conspicuous, and probably the most important as well, is the Characeæ or Stoneworts. These

plants are well known to botanists, and may readily be recognized by their jointed stems, which have at each joint a whorl of radiating leaves and branches, which are also jointed. Both stems and branches are made up of long tubular cells,* extending the length of the internodes or spaces between the joints. There is a large cell in the middle and a series of smaller ones around it, their walls touching but not usually compressing each other, so that the cylindrical shape of each cell is generally maintained and the cross section of the stem appears like a relatively large ring surrounded by a single row of small ones tangent to each other, and to the central large one. The outer, or cortical cells, are usually more or less spirally twisted around the large central one, and all the cells are thin walled and delicate, the plants containing no thick walled tissue or cells of any sort. The structure of the plant is so well marked and peculiar, that it cannot well be mistaken for that of any other, and so makes it easy to identify even small fragments of it. In some species the stems and branches are covered with a thick coating of mineral matter, are almost white, and very brittle because of this covering. These plants not only grow near the surface in shallow water of our ponds and lakes where the bottom is unoccupied by other plants, but in the deeper parts as well, and, as they thrive where light is feeble, they continue to grow throughout the year, although in winter they must grow less rapidly than in summer, because ice and snow on the surface of the lakes make less favorable light conditions.

Analytical Tests.

The sufficiency of these plants alone to fix and deposit calcium carbonate in large quantities is indicated by the following: In November, 1899, the writer collected a large mass of plants of *Chara* sp. ?, from which five stems, with a few branches, were taken at random and without any particular care being taken to prevent the brittle branches from breaking off. The stems were each about 60 cm. long, and after being dried for some days, they were roughly ground in a mortar and dried for one-half hour at 100 degrees C., dried and weighed until the weight was constant. The weight of the total solid matter obtained in this way from five plants was 3.6504 grams, 0.73 grams per plant. This was treated with cold hydrochloric acid diluted, twenty parts of water to one

*See Plate XVI.

of acid, filtered, washed, and the residue dried at 100 degrees C., on a weighed filter paper, until weight was constant. The weight of insoluble matter was 0.5986 grams; of the total soluble matter 3.0518 grams, or .6103 grams per plant. In the lake from which the material analyzed was derived from 50 to 80 plants were counted to the square decimeter of surface in the Chara beds.

A partial quantitative analysis of material from the same source, but using stronger acid to effect solution (hydrochloric acid, diluted with four parts of water,) gave the following results:

Insoluble residue.....	11.19%
Iron and aluminum oxides.....	0.722
Calcium carbonate.....	76.00
Magnesium carbonate.....	2.359
Soluble organic matter obtained by difference	9.279

The composition of the insoluble residue was obtained by heating the residue to redness in a platinum crucible for one-half hour, and the 11.19 per cent of this matter was found to consist of:

Combustible and volatile matter.....	9.243% = 82.6%
Mineral matter	1.947 = 17.4

The mineral matter was found to be:

Silica	1.787% = 92.4%
Not determined .....	.160 = 7.6

Microscopic examination showed the silica to be largely composed of whole and broken tests of diatoms, minute plants which secrete silicious shells and attach themselves to the Chara stems and branches.

The mineral matter obtained in this analysis, reduced to parts per hundred, gives the following:

Calcium carbonate	93.76
Magnesium carbonate	2.93
Silica and undetermined mineral matter	2.40
Iron and aluminum oxides .....	.89

This, with a small decrease in the mineral matter and a small amount of organic matter added, would be the composition of

ordinary marls, and would be a suitable sample to consider in connection with Portland Cement manufacture.

The large amount of silica may be explained by the fact that the material analyzed was collected at a season when diatoms are especially abundant.

The following is a copy of an analysis of the marl from the beds lying about the lake from which the Chara plants were taken. This analysis was made by L. G. Leltz, chemist for the Alma Sugar Company, season of 1900-1901:

H ₂ O and organic matter	7.438%
Sand (insoluble silica)	0.104
Carbon dioxide	38.48
Calcium oxide	52.28
Iron and aluminum oxides	0.61
Magnesium oxide	0.455
Sulphur trioxide	0.32
Soluble silica	0.0532
Chloralkalies	0.07
Phosphorus pentoxide	0.12
	<hr/>
	99.9302

It may be well to call attention to the fact that in many marls, especially those of large deposits, which the writer has examined chemically, the silica has been found to be mainly in the form of diatom shells, and hence, because of the small size and great delicacy of structure, it is available as a source of silica for calcium silicate in cement making. If such deposits as are made up largely of diatom shells were adjacent to marl beds, it is possible they might be considered as clay and be used in cement making.

Some of the silica in marl was found by mechanical analysis to consist of grains of white quartz of rather large size for sand. These may have been carried into the lake by winds, by drifting ice, by fish or by birds. The fact that these sand grains were white and of a rounded character, would point to the fish or to birds, which use such matter in their gizzards, as most probable agents of transportation, especially as no dark colored grains were found.

From the above considerations, it is evident that both because of the quality and quantity of its works, Chara may be considered an important agent in marl production, and it only becomes necessary to account for the chalky structure of the deposits to make the chain of evidence complete.

All algæ are plants of very simple structure, without tough or complicated tissues. Chara stems and branches are made up of aggregations of thin walled cells, and when the plants die the cell walls must rapidly decay and the residue of lime be left. In a laboratory experiment to determine this factor, it was found that a mass of the broken-up plants in the bottom of a tall glass vessel filled with water became decomposed very quickly, giving the characteristic odor of decaying vegetable matter, and after a few weeks all organic matter had disappeared, leaving the incrustations in tubular, very brittle fragments.

In studying the structure of marl, the writer has found that near the top of the beds there is usually a "sandy," or even a coarsely granular structure. This is noticeable at times, at all depths from which the samples are taken, i. e., in some cases it extends through the bed. Close examination of such marl shows that this coarseness is due to the remains of the characteristic Chara incrustations, and that the "sand" and other coarse material is made up of easily identifiable fragments of the coatings of stems and branches of the plant. The presence of such coarse matter near the top of the beds may be considered due to sorting action of the waves, and such surface currents as may be caused in ponds and small lakes, in shallow water, by wind action. If these agents are effective in producing the coarser parts of the deposits they may also be considered so in connection with the finer parts as well, for the matter produced by the breaking and grinding up of fragments is held in suspension for a longer or shorter time, carried about by currents, and finally sinks to the bottom in the quieter and deeper parts of the lakes. This has not been left, however, as mere conjecture, but a series of mechanical analyses of typical white marl from different localities was made. The method of analysis used was a simple one, a modification of the beaker method, used in soil analysis. The samples, chosen at random from large average specimens from the deposits under investigation, were dried in an air bath at 110° C., for sufficient time to remove any included moisture, and weighed. Each sample was then mixed with distilled water in a large beaker and thoroughly stirred with a rubber tipped glass rod, care being taken to keep up the stirring until all lumps caused by the adhesion of the finer particles to the coarser had been broken up. Care was

also taken that no more crushing should take place than was absolutely necessary.

After disintegration of all lumps was accomplished, the water with the finer particles in suspension, was poured off into another beaker, and fresh water added to the first and the material again stirred. This was continued until the water was nearly free from the finer matter and became clear on standing a short time. The coarse material left in the bottom of the beaker was dried, sorted into various grades by a series of sieves and each grade weighed. The finer material was also sorted by stirring, settling and decantation, and that of different degrees of fineness dried and weighed. The finest matter was separated from the water by filtering through a weighed filter and the water concentrated by evaporation and again filtered to remove any of the calcium carbonate dissolved in the various processes, and the final residue of water was evaporated in a watch glass and weighed. An exceedingly interesting feature of this latter experiment was the finding of a water soluble calcium salt, in small quantity it is true, but still easily weighable, and not to be neglected. The results of such an analysis of a sample from the Cedar Lake marl beds gave the following results. The sample was the one of which a chemical analysis is given above, and was taken from a hole made with a spade by cutting away the turf over the marl, then taking out sufficient marl to be reasonably sure that there was no peat or other surface matter present, and the sample used from a spadeful thrown out from two or three feet below this. From this sample about thirty grams were taken and treated as described above, and after the coarser material had been separated from the finer by washing and drying, it was passed through a set of standard gauge sieves 20, 40, 60, 80 and 100 meshes to the linear inch, after which all shells and recognizable shell fragments, sand grains and vegetable fragments up to the 60-mesh siftings were removed and weighed separately.

The following grades of material were obtained by this sorting: (1) That too coarse to pass through the 20-mesh sieve, (2) that held by the 40-mesh sieve, (3) that held by the 60-mesh, (4) that held by the 80-mesh, (5) that held by the 100-mesh, (6) that which passed through 100-mesh, (7) that which was filtered out, (8) water soluble salts, (9) shells, shell fragments, etc.

Analysis (1) is the result of the analysis made and the material graded as described:

	Cedar Lake Marl.	Littlefield Lake Marl.	Coldwater Marl.	Residue from dead Chara.
	1.	2.	3.	4.
Grade (1).....	32.25%	31.52%	0.36%	1.12%
" (2).....	6.06	14.48	3.53	24.43
" (3).....	7.58	12.76	6.51	14.63
" (4).....	2.90	2.56	3.34	8.26
" (5).....	4.81	6.74	6.44	7.81
" (6).....	15.64 ⁽¹⁾	30.42	28.99	23.83
" (7).....			49.12	
" (8).....	30.52	0.27	1.02	0.39
" (9).....	0.28	1.04	0.69	0.12
	100.04	99.89	100.00	90.59

⁽¹⁾In this case determined by drying down the residue and weighing.

A second analysis was made from a specimen made up of twenty samples taken by boring with an augur over about one-half the deposit at Littlefield Lake, Isabella County, most of the samples coming from a depth of at least twenty feet below the surface of the deposit. This analysis is given as 2:

Grade (1).....	= 31.52%
" (2).....	= 14.48
" (3).....	= 12.76
" (4).....	= 2.56
" (5).....	= 6.74
" (6) }	
" (7) }	= 30.42
" (8).....	= 0.27*
" (9).....	= 1.04
	<hr/> 99.89

A third sample from the holdings of the Michigan Portland Cement Company, at Coldwater, a fine high grade white marl, very powdery, gave Analysis 3:

Grade (1).....	= 0.36%
" (2).....	= 3.53
" (3).....	= 6.51
" (4).....	= 3.34
" (5).....	= 6.44
" (6).....	= 28.99
" (7).....	= 49.12
" (8).....	= not determined.
" (9).....	= 0.69
Soluble matter and loss by difference.....	= 1.02
	<hr/> 100.00

*The soluble matter contains a certain undetermined amount sodium and potassium salts as well as soluble calcium compound.

These samples represent (1) the central, (2) the north central and (3) the southern parts of the Lower Peninsula of Michigan, respectively, and may be taken as typical of the marl deposits of Michigan. When it is stated that, in general, it is easily possible to recognize with a simple microscope, particles which are held by the 100-mesh sieve or even those which pass through it, if the finer matter has been carefully separated by washing, as characteristic *Chara* incrustation, or *Schizothrix* concretions, it will be seen that these results show conclusively that a large part of the marl from these three samples is identifiable as of algal origin and studies of the marl from other localities give similar results. The Cold-water sample (3) was exceedingly fine in texture, and it was difficult to avoid loss in sorting and weighing, as every current of air carried away some of the particles, and some also adhered to the sieves and weighing dishes, in spite of all the usual precautions against such loss. Even this sample shows nearly fifty per cent of easily identifiable *Chara* incrustation. The fineness of the particles in a given marl bed varies much in different parts of the bed and the degree of fineness is probably largely dependent upon the conditions of current and wave action under which the bed was formed as noted in another place. This fact was noted at Littlefield Lake, where samples of marl were collected along exposed shores near the wave line, which were ninety-five per cent coarse fragments of *Chara* incrustation and *Schizothrix* nodules, while in other parts of the shore line the marl was of such fineness that it was like fine white clay.

References in Literature.

Fragments of the *Chara* incrustation are generally easily recognized, even when of minute size, because they preserve, usually very perfectly, but sometimes less so, the peculiar form of the stem, branches, leaves and fruits of the plant. This fact has led various authors, both geologists and botanists, to note the occurrence of "fossil" *Chara* stems and fruits in the beds of lakes and even in marl beds. Sir Charles Lyell* as early as 1829 described a marl bed in Forfarshire, mentioning as especially interesting the finding of "fossil" *Chara* fruits and stems. In two editions of the "Principles of Geology,"† which have been consulted, the same

*Lyell "On a recent formation of fresh water Limestone in Forfarshire." Transactions Geol. Society, 2, p. 241, 1829.

10th Ed., Vol. 3, p. 360, 1842; 9th Ed., p. 766-7, 1853.

writer points out the importance of the remains of *Chara* to the geologist in characterizing entire groups of strata, and describes and figures the fruits and stems of recent species *Chara hispida* from Bakié Loch, Forfarshire. He also mentions the occurrence of *Chara* in abundance, in several lakes in New York State. Geikie* mentions the occurrence of *Chara* as a true fossil in the beds of "a form of travertine from which fresh water shells and a rich assemblage of plants have been obtained." These beds are "lower Eocene, the limestones of Rilly and Sizanne, Basin of Paris." *Chara Lyelli* fruits are figured.

Kerner† says, "The spore fruits of Stoneworts (Characeæ) have been found over and over again inclosed in these formations of lime." He points out also that it is possible for calcareous strata of great depth to be produced by plants in fresh water.

Schimper‡, Solms-Laubach§, Seward|| and Wesenberg-Lund¶ all mentioned these plants as agents of deposition of lime formations, the latter especially showing the plants able to produce extensive deposits of what he terms "Characee-lime" in the lakes of Denmark.

Mosely**, in speaking of the deposits of "tufa" about the remarkable springs near Castalia, Ohio, mentions the fact that the deposit "is composed mostly of petrified *Chara*."

Even when this structure is destroyed, as may be the case with the thin and incomplete incrustations, it is frequently possible to recognize fragments of the tubes with the compound microscope. Finally in *Chara* as in other plants the incrustation is distinctly crystalline in the ultimate form of the constituent particles, and when it has disintegrated, the crystals and their fragments are found to constitute a large per cent of the finer particles of the resulting marl. On the growing tips of the younger branches and leaves of *Chara*, numbers of isolated crystals of calcium carbonate may be seen, and farther back the crystals become more numerous, then coalesce into a thin fragile covering, and finally on the lower part of the plant the covering becomes dense and thick. It is evident, therefore, that the decay of the younger parts of the plants would furnish a mass of more or less free or loosely aggregated

*A. Geikie; Text-book of Geology, 2nd Edition, p. 853, p. 859, 1869.

†Kerner and Oliver; Nat. Hist. of Plants, Vol. 1, p. 261.

‡Schimper, W. Ph. "Traité de Paléontologie Végétale," Vol. 1, p. 276, 1869.

§Solms-Laubach, Fossil Botany, pp. 36-37, 1891.

||Seward, A. C., Fossil Plants, v, p. 69, pp. 222-228, 1898.

¶Wesenberg-Lund, C., loc. cit., pp. 155-156.

**Mosely, E. L., Sandusky Flora, p 87, Ohio State Academy of Science, special papers, No. 1, 1899.

crystals of microscopic size which would retain their crystalline form, in some degree at least, for an indefinite time and be recognizable, hence the presence of these micro-crystals in marl is another indication of the origin of the deposits.

Source of Thick Crusts.

The larger fragments of *Chara* incrustation as found in marl are frequently much thicker and heavier than those which occur among the fragments of recent origin, namely those obtained from any part of living, vigorously growing *Chara* from beds of the plant existing in the ponds from which the marl may have been obtained.

While the subject needs further investigation, it is probable that such thickened incrustations have originated in several ways, the principal ones being, if the writer's notes have any bearing on the subject, as follows:

First, On short, stunted plants that grow for a long time on unfavorable soil, such as sand, or pure marl. Such plants have relatively very short internodes, and generally thick incrustations.

Second, From the growth of the lime secreting blue-green algæ, such as *Schizothrix*, *Zonotrichia*, etc., either upon living *Chara*, or upon fragments of broken incrustation as a nucleus.

Third, From the inclusion of the fragments within the nodules formed by the growth of the blue-green incrusting algæ in shallow water and the subsequent destruction of the nodules by wave or other disintegrating action, in which case, the thickened fragments may be left either free, or attached to other material. In this way, several fragments may be cemented together and such aggregations have been observed by the writer.

Fourth, By the deposition of calcium carbonate on fragments of incrustations, a deposition caused by the decomposition of soluble organic calcium salts, left free in the water by the decay of dead *Chara* plants, through the reducing action of chemical compounds derived from the decay of organic matter, or the growth of bacteria, or both.

Fifth, By the deposition in more or less coarsely crystalline form of the calcium carbonate which is dissolved by water percolating through the marl. This is probably considerable in amount and takes place in a manner analogous to, if not identical with, the formation of concretions in clays and shales. It is probable that in this way, the crystals may be formed which rather rarely are

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found filling the cavities left by the large axial cells in *Chara* incrustations. The fact that in the great majority of cases these cell cavities are entirely empty, or simply mechanically filled with fine particles of marl, is the most serious objection to considering that this form of chemical precipitation is an important one in the history of marl, but that it is occasionally operative is most probable.

Sixth, It is possible that the thick incrustations may have been formed at some earlier period in the history of the lakes when conditions were more favorable for the development of *Chara* and its activities were greater. This is not probable, however, for the thick incrustations are frequently found from the surface of the marl beds throughout the deposits.

A check analysis was made of a specimen of material made up from the washings and fragments of a mass of *Chara* plants collected from Cedar Lake, and allowed to die slowly, and break up in water kept cold and fresh by conducting a small stream from the hydrant through it. The plants gradually died, broke up and settled to the bottom of the containing vessel, and seemed to undergo farther disintegration there, eventually forming a relatively finely divided deposit which was of rather dark color when wet. A quantity of this was dried at 100 degrees C., some of the larger and longer fragments of stems were removed and the residue weighed and subjected to the same treatment as the marl samples. Ten grams was the amount taken, and the analysis yielded the results given by No. 4, page 76.

It will be seen that nearly as much fine matter was present in this material as in the finest of the marls analyzed and that the finer grades of sifted material are quite as well represented, as in the finer marl. The material is somewhat more bulky for a given weight and is perhaps slightly darker in color, but not much more so, than many samples of marl. Grade for grade it is identical in appearance and structure to the marl samples, and the only possible difference that can be detected is the slightly greenish tint due to the organic matter present in the plant residue. It is also noticeable that the larger pieces do not show as thick an incrustation as do larger pieces from the marl samples, and, of course, *Schizothrix* and other coarse matter is not present.

It will be seen by inspecting the analyses that shells and recognizable shell fragments are but a very insignificant part of the

total quantity of the marl. It is surprisingly small when all things are taken into account. While it is probably true that not all the minute shell fragments have been separated in any of these analyses, it is also true that the weight of such particles as were overlooked, is more than counterbalanced by marl fragments, which are included within the cavities of the whole shells and adhere to both broken and whole shells, in crevices and sculpturings, in such a way as to refuse to become separated in the processes of washing out the marl. The whole shells are mainly small fragile forms, many of them immature, and it is evident that they would be broken by any action that would crush the *Chara* incrustation.

§ 6. Marl beds without *Chara*.

As is easily observed in many marl lakes, and as has been pointed out to the writer by several students of lake life, marl beds are often found in parts of lakes in which there are no well developed beds of *Chara*.

At least two explanations of this may be offered without appealing to other modes of marl formation, both of which may be applicable, either independently or together, in individual cases. The first of these is that such beds of marl were formerly occupied by *Chara*, but for some reason or reasons, the conditions for growth became unfavorable and the colonies disappeared, or became insignificant and escaped notice. The second explanation takes into account the action of waves and currents upon the deposits near thriving growths of *Chara* and assumes that the more remote marl deposits may be the result of such action combined with the transporting power of the surface and other currents which may exist in the lakes.

In support of the former consideration are the notes of Dr. Henry B. Ward on Pine Lake in the Traverse Bay Region of Michigan. He says:*

"Pine Lake has undoubtedly undergone some considerable modification, within recent geological times. The old outlet to the northward is easily traced through a line of tamarack swamp to Susan Lake;—thence to Lake Michigan, it follows a small stream which is at present the outlet of Susan Lake. The marl bottom which underlies a very considerable part of Pine Lake can by borings be found not far from the surface at various points around the lake. The gravel and glacial drift are evidently at present being washed out into the lake over the marl and the thick-

*H. B. Ward, "A Biological Examination of Lake Michigan, in the Traverse Bay Region," Bull. Mich. Fish Com. No. 6, p. 65.

ness of the latter decreases gradually as one recedes from the shore. Mollusca are not very abundant and while the species recorded by Mr. Walker are recent and most of them at least found in this locality at present, the existing conditions are inadequate to account for such a bed of marl, and I am inclined to believe it to be the bed of an older lake now gradually disappearing."

He also says:

"On the marl one finds no living thing save here and there scanty tufts of dwarfed *Chara*, which was never found in fruit: it was uniformly encrusted by heavy calcareous coating."

Here, as the author so clearly points out, there has been a change in the lake within recent geological time and with this it is possible that the agencies producing the marls have become less active. The fact that Dr. Ward mentioned *Chara* as growing abundantly on the south arm of the lake would point to that plant having been more abundant formerly than now, but as the lake has not been visited, nor specimens of the marl seen by me, no claim is made that the beds described were formed by *Chara*.

§ 7. Association of marl and peat.

Chara may also be looked upon as an important agent in giving the peculiar distribution to marl which has been noticed by everyone who has "prospected" beds of this material. The fact is frequently noticed that beds of several, and even as much as twenty or more, feet in thickness will "run out" abruptly into beds of "muck," or pure vegetable debris (peat), of equal thickness. This distribution may show that up to a certain time conditions unfavorable to the growth of *Chara* and favorable to other plants obtained, until a depth of water was reached at which *Chara* was able to occupy the bed of muck, covering it from the bottom up, and holding the steep slope of the muck in place by mechanically binding it there by its stems and the root-like bodies by which it is connected with the mud. From the time when the *Chara* began its occupation of the muck the amount of organic matter left would decrease, and the amount of calcareous deposit would increase, until the latter predominated. The disturbing factors of currents and waves can be disregarded, for these abrupt unions of marl and muck are found, so far as the observations of the writer go, in most sheltered places, and not where either currents or waves could ever have operated with any force or effectiveness. Moreover, in a lake where the marl is evidently now actively extending, the slope was observed to be nearly perpendicular, and the steep banks thus

formed were thickly covered with growing *Chara* to the exclusion of other large forms of plant life, and the lower parts of the growing stems were buried in mud which was mainly pure marl.

§ 8. Turbidity due to marl.

That the finer parts of marl deposits may readily be moved from place to place in lakes in which they exist and where any part of the deposit is exposed to wave action, seems demonstrated by a series of studies, suggested by the milky appearance of the waters of some marl lakes. This has been considered by some investigators as possibly due to the presence of calcium carbonate, precipitated from the water, either by liberation of dissolved carbon dioxide or by a change of temperature of the water after it has reached the lakes.* The writer has not found among the marl lakes of Central Michigan, that those with turbid water were common, even where marl banks were apparently forming with considerable rapidity. "Merl" or Marl Lake in Montcalm County, situated on the same stream as Cedar Lake, and a mile or more below it, is, however, one of the lakes in which the water is usually of almost milky whiteness and has sufficient suspended matter in it to render it nearly opaque for depths over a meter or a meter and a half. The conditions in this lake are widely different from those at Cedar Lake and other marl lakes in the vicinity and are suggestive of the cause of the turbidity. At Cedar Lake, there is a border of grassy and sedgy marsh extending around the lake on three sides, that is generally underlain by marl, and the lake bottom slopes sharply and abruptly from the edge of the marsh to a depth of at least 10 meters. In other words the lake is simply a deep hole, with steep sides, and, perhaps, represents the deepest part of the more extensive lake which formerly occupied the area included by the marsh and marl beds. This marsh covering is generally found upon all the marl beds of the region and the lake may be said to be typical, for the locality in which it lies, for there are several others near by, which are practically identical in essential points of structure.

At Marl Lake, however, the filling of the lake has not reached the same stage. There is practically no open marsh, but the lake is shallow for seventy-five or a hundred meters from the shore, then abruptly deepens to an undetermined depth over a relatively small area. The bottom over the shallow area is of pure white marl and

*25th Annual Report, State Geologist of Indiana.

the water is apparently not more than sixty or seventy centimeters deep at the margin of the central hole, while near the shore it is scarcely a third as deep. In brief, here is a lake in which there is a broad platform of marl surrounding a deep hole, which again, is all that remains of the deep water of a lake which is filling with marl. Boring shows that the bed of the lake is nearly as far below the surface under the marl platform as where the marl has not yet been deposited. Upon the shoreward margin of the platform, and in small areas farther out upon it, the turf-forming plants are beginning to establish themselves, but as yet they have not made any marked impression, seeming to have a hard struggle to get a foothold.

The conditions are then, a broad area of shallow water, overlying a wide platform of marl, which, if a strong wind should reach it, would be stirred to its depths, and with it, the lighter parts of the marl upon which it rests. The marl thus stirred up, in turn is carried to all parts of the lake by surface and other currents and makes the water turbid.

These facts led to an investigation into the rapidity with which marl once stirred up would settle out of perfectly still water and some interesting results were obtained. The experiments were made as follows:

(1) A glass tube 1.58 m. long and 2.5 cm. wide was filled with distilled water, and a quantity of finely divided marl was added and thoroughly mixed by shaking. The tube was then clamped in a vertical position and left perfectly still until the marl had settled out, record being kept of the rate of settling. At first the heavier particles settled rapidly, forming as does clay in settling out from water with which it is mixed, distinct stratification planes; which after a few days disappeared, and only the lighter parts of the marl remained in suspension. These were distinctly visible for five weeks on looking through the tube towards a good light, and at the end of six weeks a black object lowered into the tube, in a well lighted room, was not visible beyond 90 cm. from the surface of the water.

(2) A glass cylinder with a foot, 38 cm. high and 7 cm. wide, having a capacity of a little more than a litre was nearly filled with distilled water and the residue from the washings of a sample of marl from which the coarser matter had been separated, was thoroughly shaken up in it. This was left to subside as in

the first experiment, and at the end of ten weeks the bottom of the vessel was barely visible. The results obtained by Barus,* in his work on the subsidence of solid matter in suspension in liquids, show that settling is much more rapid in water containing dissolved salts even in small proportion than in distilled water, so check experiments were made as follows: (1) A cylinder approximately the size of the one used in the second experiment above, was filled with water in which a small amount of calcium chloride had been dissolved, and ammonium carbonate was added until a precipitate was formed. The contents of the jar were then stirred thoroughly and left to settle. In three days the entire precipitate had settled out and the liquid was clear. In this case, however, it was deemed probable that the conditions were not at all like those occurring in nature and a second experiment in which the marl was shaken up with the ordinary natural water of the region, obtained from a river partly fed by marl lakes. In comparison with distilled water the subsidence was notably more rapid than from distilled water for the finer part of the marl, but for fifteen days there was distinct turbidity noticeable.

These results indicate that if for any cause the marl in one of the marl lakes is stirred up effectually, as it may be where the beds are exposed to wave action, that the water will remain turbid for some time, and the chances are that even in summer time there will be sufficiently frequent high winds to keep the water always turbid. It may be stated that in some of the lakes which have been studied by the writer the marl has filled the entire lake to within a meter or less of the surface of the water, with some parts even shallower. Until such shallows are occupied by plants and turfed over, the water is likely to be turbid from the mechanical action of waves upon the deposits. At Littlefield Lake, described elsewhere,† the water is only slightly turbid, although there are extensive marly shallows and exposed banks, but there the body of the water is extensive and of considerable depth, while the greater part of the exposed marl is granular and the particles too coarse to be held long in suspension, and the finer parts too small and too well protected to be reached by effective waves, so that the amount of suspended marl is not great enough to produce marked turbidity in the entire body of water. It is worthy of note that the residue

*Subsidence of fine solid particles in liquids, Carl Barus, Bull. U. S. Geol. Survey, No. 36.

†Journal of Geology, VIII, No. 6, and this report, p. 92.

filtered out from the sample of Chara fragments (Analysis 4) was sufficiently fine to give a marked turbidity to distilled water for several days and at the time of filtering had not subsided. It is difficult to account for the fact that the deeper parts of marl lakes are generally free from any thick deposits of a calcareous nature. Lack of records of sufficient exploration makes any statement purely tentative, but about 7-9 meters seems to be limit of depth of the recorded occurrence of Chara plants.* The remains of the plants then would only accumulate in place, over bottoms above that depth, and the material reaching greater depths would have to be that held in suspension in the water, hence be relatively small in quantity and accumulate slowly. A probable additional cause is that in the greater depths (i. e., over 9 meters) a greater abundance of dissolved carbon dioxide, due to the decomposition of organic matter in relatively cold water under pressure, dissolves the fine particles of marl which reach these depths, but at present no data are at hand on which to base a conclusion as to the exact efficiency of this cause.†

§ 9. Conclusions.

From these investigations it seems: First, that marl, even of the very white pulverulent type, is nearly made up of a mixture of coarse and finer matter, covered up and concealed by the finer particles, which act as the binding material. Second, that the coarser material is present in proportion of from 50% to 95% of the entire mass. Third, that this coarser material is easily recognizable with the unaided eye and hand lens as the incrustation produced on Schizothrix and Chara, principally the latter, to particles less than one one-hundredth of an inch in diameter. Fourth, that the finer matter is largely recognizable under the compound microscope as crystalline in structure and derived from the algal incrustations by the breaking up of the thinner and more fragile parts or by disintegration of the younger parts not fully covered. Fifth, that some of this finer matter is capable of remaining suspended in water a sufficient time, after being shaken up with it, to make it unnecessary to advance any other hypothesis to explain the turbidity of the water of some marl lakes, than that it is caused by mechanical stirring up of the marl by waves or other

*C. Wesenberg-Lund: Loc. cit., p. 156. A. J. Pieters: Plants of Lake St. Clair. Bull. Mich. Fish Commission, No. 2, p. 6. Compare, however, reports of the Indiana Survey.

†But see tests 11 and 12, etc., of water in the Cloverdale district, p. 46. L.

agency. Sixth, that shells and shell remains are not important factors in the production of the marl beds which are of the largest extent. Seventh, there is in marl, a small amount of a water soluble calcium salt, possibly calcium succinate, readily soluble in distilled water after complete evaporation of the water in which it was first dissolved.

§ 10. Method of concentration by Chara.

After these facts were developed studies were undertaken to determine the method of concentration and precipitation of the calcium carbonate by Chara. Some such studies have already been reported upon by various authors, but none of these have apparently been exhaustive, and the original papers are not at hand at the present writing, although abstracts of the more important ones have been seen.

As has been already indicated elsewhere, the calcium carbonate is present on the outside of the plant as an incrustation and this is made up of crystals, which are rather remote and scattered on the growing parts of the plants and form complete covering on the older parts, which is uniformly thicker on the basal joints of the stems than it is on the upper ones. Considering the hypothesis that the deposition of the salt was the result of purely external chemical action, as not fully capable of satisfying all the existing conditions, the formation of the incrustation was taken up as a biological problem and investigation was made upon the cell contents, at first, microscopically by the study of thin sections. Various parts were sectioned while still living and the attempt was made to find out if the calcium carbonate were present, as part of the cell contents in recognizable crystalline form. In no case were such crystals found, although reported by other observers.

Next an attempt was made to determine the presence of the calcium in soluble form in the cell contents by the use of a dilute neutral solution of ammonium oxalate. An immediate response to the test was received by the formation of great numbers of minute characteristic octahedral crystals of calcium oxalate on the surface and embedded in the contracted protoplasmic contents of the cells. The number of these crystals was so large and they were so evenly distributed through the cell contents, that it was evident that a large amount of some soluble calcium salt was diffused through the cell sap of the plant. The next step was to isolate this compound and to determine its composition. A considerable

quantity of the growing tips of Chara were rubbed up in a mortar and the pulp was thoroughly extracted with distilled water. This water extract was filtered, concentrated by evaporation on a water bath, and tested to determine the presence of calcium. An abundant precipitate was again obtained by using ammonium oxalate, which on being separated and tested proved to be calcium oxalate. It was evident that the calcium salt in the plant was stable and readily soluble in water. This latter fact was farther demonstrated by evaporating some of the extract to dryness and again taking it up with water. Almost the entire amount of the calcium salt was redissolved, only a small portion of it becoming insoluble, precipitating as the carbonate. This ready solubility demonstrated that the salt was not derived from the incrustation on the portions of the plant used, and the same fact excluded from the list of possible compounds, salts of the more common organic acids found in plant juices. Qualitative chemical tests were, however, made to determine, if possible, whether any of these acids were present, with negative results, and it was demonstrated by this means that there was but a single salt present and not a mixture. Search was then made to determine the acid present and a result was obtained which was so unexpected that it was seriously questioned, and the work was gone over again. The second result confirmed the first, and the work of ascertaining the correctness of these two results was turned over to Mr. F. E. West, Instructor in Chemistry in Alma College, who had special training and much practice in organic analysis. His work was done entirely independently with material gathered at a different season, and by another method of analysis, but his results were identical with my own and show that calcium exists in the water extract of Chara as calcium succinate, $\text{Ca}(\text{C}_4\text{H}_4\text{O}_6)$. The fact that the succinate is one of the few water soluble salts of calcium and that there is a soluble salt of the metal in the cell sap of the plant, makes it probable that this is the compound which the plant accumulates in its cells. It is not yet possible, from actual investigation, to explain the method by which the calcium salt is abstracted from the lake water, where it exists as the acid or bicarbonate, or as the sulphate,* in small per cent, and concentrated in the cells of the plant as the calcium succinate and later deposited upon the outsides of the small cells as the

*The formation of CaCO_3 incrustation by Chara in water impregnated with CaSO_4 , accompanied by the liberation of H_2S is reported in a book called the "Universe."

normal or monocarbonate in considerable quantities. Culture experiments which were undertaken by the writer to determine under what conditions of soil, light and temperature *Chara* thrives best, incidentally demonstrated that the plant actually gets its lime from the water about it and not from the soil. One of the soils which was used as a substratum in which to grow plants was pure quartz sea-sand, which had been thoroughly washed and tested with acid to be certain that no calcium salt was present in it. The plants grew in this medium readily, and on the newer parts, developed nearly if not quite as many calcium carbonate crystals as plants growing on pure marl. It should be apparent, however, to even the casual observer, that the plants cannot take all the lime they use in forming incrustations from the soil, for if they did the marl beds, being made up principally of *Chara* remains, would never have accumulated, for the material would have been used over and over again and could not increase in amount.

In the present state of our knowledge of the life processes of aquatic plants it seems hardly possible to state the probable method of formation of the calcium succinate or even the probable use of it to the plant and no attempt will be made by the writer just here to do so. It does seem probable, however, that this compound accumulates in the cells until it reaches sufficient density to begin to diffuse through the cell walls by osmosis. Outside the cells it is decomposed directly into the carbonate, possibly by oxidation of the succinic acid by free oxygen given off by the plants, possibly, by the decomposition of the acid by some of the organic compounds in the water due to bacterial growth in the organic debris at the bottom of the mass of growing *Chara*. The water extract of *Chara* rapidly changes on standing, undergoes putrefactive decomposition, becomes exceedingly offensive in odors developed, and a considerable quantity of calcium carbonate crystallizes out on the bottom and sides of the containing vessel, while the succinic acid disappears, gas being given off during the process more or less abundantly. Whether these changes take place on the outside of living plants has not yet been determined.

In regard to the species of *Chara* which seems to be the active agent in precipitation in the lakes of Central Michigan, it is the form commonly known as *Chara fragilis*, but it is probable that careful study of the species throughout the range of the marl will reveal, not a single form, but a number of allied species, engaged in

the same work. It may be well to suggest that in lakes to which silt is brought by inflowing streams, or which have exposed shores where the waves are constantly cutting and stirring up rock debris, the more slowly accumulating marls will be either so impure as to be worthless, or so obscured as to escape notice altogether, even where *Chara* is abundant. It may also be pointed out that shallow water, strong light, and a bottom of either clay, sand, or muck, present conditions favorable for the growth of the higher vascular plants, and that these cause such rapid accumulation of vegetable debris that the calcareous matter may be hidden by it, even when *Chara* is a well marked feature of the life of a given lake.

This view is amply supported by the presence of large accumulations of *Chara* plants heavily incrustated with calcium carbonate, at the storm-wave line along the shore of Saginaw Bay, in Huron County. These windrows, however, soon disappear, leaving nothing more than a limy layer in the sand, scarcely to be distinguished from the rest of the wave-washed shore, and ultimately all trace of them is lost.

§ 11. Blue-green algæ and their work.

Another plant form, like *Chara*, an alga, but of a much lower type, which is concerned in the formation of marl, is one of the filamentous blue-green algæ, determined by Dr. Julia W. Snow, of Smith College, to be a species of *Zonotrichia*, or some closely related genus. The work of this species is entirely different in its appearance from that of *Chara*, and at first glance would not be attributed to plants at all. It seems to have been nearly overlooked in this country, at least, by botanists and geologists alike, as but three references to it have been found in American literature.* Curiously enough, however, material very similar, if not identical, to that under consideration has been described from Michigan in an English periodical devoted to algæ.† In this the alga is identified as *Schizothrix fasciculata* Goment. Mr. F. S. Collins of Malden, Mass., has identified *Schizothrix fasciculata* as present in the concretions from Littlefield Lake, but does not specify it as the form which has the calcareous covering. The plant grows in relatively long filaments formed by cells growing end to end, and as they grow, the filaments become incased in calcareous

*McMillan: Minn. Plant Life, 1899, p. 41. Penhallow: Botanical Journal, 1896, p. 215; J. M. Clarke. "The Water Biscuit of Squaw Island, Canandaigua Lake, N. Y." Bull. of the N. Y. State Museum, No. 39, Vol. 8, p. 185, 1900.

†G. Murray: Phycological Memoirs No. XIII, 1895, p. 9, Pl. XIX.

sheaths. The feature of the plant which makes it important in this discussion, however, is its habit of growing in masses or colonies. The colony seems to start at some point of attachment, or on some object like a shell, and to grow outward radially in all directions, each filament independent of all others and all precipitating calcium carbonate tubules. The tubules are strong enough to serve as points of attachment for other plants, and these add themselves to the little spheroid, and entangle particles of solid matter, which in turn are held by new growths of the lime-precipitating *Zonotrichia*, and thus a pebble of greater or less size is formed which to the casual observer is in no wise different from an ordinary water rounded pebble. These algal calcareous pebbles show both radial and concentric structure and might well be taken for concretions formed by rolling some sticky substance over and over in the wet marl on which they occur but for the fact that a considerable number of them show eccentric radial arrangement, and that the shells of accretion are likewise much thicker on one side than on the other, and finally, because the side which rests on the bottom is usually imperfect and much less compact than the others. The pebbles are characteristically ellipsoidal in shape. The radial lines, noticeable in cross sections of the pebbles, are considered by the writer to be formed by the growth of the filaments while the concentric lines probably represent periods of growth of the plants, either seasonal or annual. Included within the structure are great numbers of plants, besides the calcareous *Zonotrichia*, among them considerable numbers of diatoms, and it is probable that a large part of the algal flora of a given lake would be represented by individuals found in one of these pebbles. It is probable that to a certain extent they disintegrate after the plants cease to grow, for they are never very hard when wet. It is possible to recognize them, as lumps of coarser matter, even in very old marl, and the writer has identified them in marl from Cedar Lake, which was taken from a bed a foot or more above, and several rods away from, the lake at its present level. From the fact that these pebbles have been found, by the writer in four typical marl lakes in different parts of Michigan (in Zukey Lake and Higgins Lake by Dr. A. C. Lane, who was struck with their peculiar character) and have been reported from a number of others by Mr. Hale and other marl hunters, it is probable that they have a wide distribution in the State and are constant if not

important contributors to marl beds. It may be said in passing that the limy incrustations which are found upon twigs, branches, shells, and other objects in lakes and streams, and called generally "calcareous tufas," are of similar origin and are formed by nearly related, if not by the same plants that form the pebbles.

Studies have been begun by the writer to solve, if possible, some of the questions which have arisen in connection with the statements embodied in this paper, but enough has already been done to show that these forms of fresh-water algæ are important lime-precipitating agents now, and to suggest the possibility that in all likelihood they have been more active in former geological times, and that, as has been suggested again and again by botanists, the formation of certain structureless limestones, and tufa deposits may have been due to their work.

§ 12. Littlefield Lake, Isabella County.

Early in June, 1900, the writer visited this interesting body of water, and from its peculiar form, and the deposits about it, it seemed worthy of special description.*

The country about the lake is of a well-marked morainal structure, the till, however, being sandy in places, and noticeably gravelly and bouldery throughout, and was formerly heavily covered with pine. The lake occupies a deep depression in a trough-like valley, surrounded by moderately high morainal hills, and from its apparent connection with a series of swamp valleys, suggests a glacial drainage valley, but as it was not followed for any distance, its origin was not determined.

The lake itself is about one and one-half miles long, by three-fourths of a mile broad in the widest part, which is near the middle of the long axis and the shape is that of an irregular blunt ended crescent. It was said to be over eighty feet deep in the deepest part, but no soundings were made by the writer. Its greatest length is from northwest to southeast, with the outlet at the southern end. There are no considerable streams entering it, but at least three small brooks fed by springs from the surrounding hills were noted flowing in, and the outlet is of such size that a boat may be easily floated on it at high water, although its level is maintained during the summer by a dam about two miles below the lake. The main inlet was not seen by the writer.

*See Plate XIX.

The shore lines are relatively regular, especially on the east and north sides, the convex side of the crescent, with banks twenty or more feet high close to the water on the east, while on the west side are two rather deeply indented bays. At either end are three small ponds, parasite, or daughter lakes, and surrounding the entire shore except on the eastern side, and the northeastern, or inlet, end is a cedar swamp which is underlaid by marl. The outlet is through the most southerly of the daughter lakes, and the entire shore of the lake is formed by beautifully white marl, the exposures varying in width from a few feet to three or four rods in width, so that as one overlooks the lake from one of the surrounding hills it seems to lie in a basin of white marble.

There are three small islands in the lake, two relatively near together at the northern end, and one quite near the shore at the south end. These islands are also of marl, covered partly with a thin layer of vegetable matter and a scanty growth of grass, bushes and cedar. There is a visible connection, under water, between at least one of the islands and the shore, and it is probable that all of them are thus connected by submerged banks. The marl on the islands is from twenty-five to thirty feet deep, with sand below.

Explorations in the swampy border of the lake, show that the shore was formerly more irregular than now, and that the marl extends back from the water in some places for at least one-fourth of a mile, gradually becoming more and more shallow until the solid gravel or clay is reached. The marl is frequently thirty feet deep along the shore and at no place was it found to be less than fifteen feet deep at the present shore line, the shallowest places being along the shore where the high bank comes down near the water. The deepest vegetable deposit, or peat, found in one hundred and fifty borings in all parts of the deposit was three feet. The main deposits of marl are about the southeast end and along the western side of the lake, with a body of considerable size, underlying a swampy area at the north end. Of the six daughter lakes, four are very small, an acre or two in extent and entirely surrounded by deep marl, the connection between three of them and the mother lake being shallow and narrow, a few inches deep, and a few feet wide, and only existing at high water, while two of the other three are of much larger size, with marl points extending out from either side of the straits which are still relatively wide and deep.

Of the two bays on the west side of the lake, one is much narrower than the other and at the mouths of both, marl points are extending towards each other to a noticeable degree.

At all points along the shore, the slope of the marl is very abrupt from the shallow water to the bottom, always more than forty-five degrees, and frequently nearly ninety, this steepness being noticeable in the small as well as in the parent lakes, while on the east side of the island, at the south end of the lake, the wall of marl seemed positively to overhang, although this appearance was probably due to refraction.

The texture of the deepest part of this marl deposit is apparently that of soft putty, a sounding rod passed through it with comparative ease, and samples brought up have a yellowish or creamy color, which disappears as they dry, leaving the color almost pure white. At the surface the marl is coarser, slightly yellowish and more compact. Where it lies above the water line it is distinctly made up of granular and irregular angular fragments, resembling coarse sand, but the fragments are very brittle, soft and friable, and may be converted into powder by rubbing between the thumb and fingers.

On the parts of the shores where apparently the wave action is chiefly exerted, there are small rounded calcareous pebbles, mixed with molluscan shells, drift material and considerable quantities of stems, branches and more or less broken fragments of the alga, Chara, all parts of which are heavily incrustated with calcareous matter. This Chara material was often piled up in windrows of considerable extent at the high water mark.

The marl banks of the lake, from a little below the water's edge down as far as could be seen, were generally thickly covered with growing Chara, at the time of the writer's visit and wherever a plant of it was examined it had a heavy coating of limy matter, which was so closely adherent to the plant, as to seem a part of it, and because of this covering, the plants were inconspicuous, and would easily escape notice.

Little if any other vegetation of any character was growing in the lakes at this season. Indeed, from the steep slope of the banks of marl, it would be hardly possible for any considerable amount of vegetation of higher types than algæ, to flourish here, because of the lack of light at the depth at which it would have to grow to establish itself.

As *Chara* of several species, is known to occur within our limits, at depths as great as thirty feet, and probably grows at even greater depths, where the water is clear and the bottom soil is of the right character, i. e., of clay, finely divided alluvial matter, marl, etc., it is apparent that there must be an immense growth of this type of plants in such a lake as the one under discussion. That there is an abundance of *Chara* in Littlefield Lake is shown by the amount of drift material, composed of the plant, which had accumulated in heaps at the high water wave marks along the shore at various places.

From even a casual inspection of this drift accumulation, it is evident that it is the source of much of the granular and sandlike marl on the beaches, and in the coarse upper layers of the deposit. This wind and wave accumulated material was dry and bleached, and was very brittle, so fragile indeed, that a mere touch was generally sufficient to break it into fragments and it passed by insensible gradation from the perfect, unbroken, dried plant form at the high water mark, in which every detail, even the fruit, is preserved, to inpalpable powder at, and below the water's edge.

In other words we have in *Chara*, a plant of relatively simple organization, and one able to grow in abundance under most conditions of light and soil which are unfavorable to more highly developed types, a chief agent in gathering, and rendering insoluble, or precipitating, calcium and other mineral salts brought into the lake from the clays of the moraine around it by the stream, spring and seepage waters. After precipitation is accomplished and the plant is dislodged, or dies, it drifts ashore, where after decomposing and drying out the small amount of vegetable matter, the various erosive agents at work along shore break up the incrusting chalky matter, and the finer fragments are carried into deeper water, the coarser are left along the lines of wave action.

The pebbles mentioned above as occurring on parts of the shore, are also the result of the development and growth of an alga, *Zonotrichia* or a nearly related genus, a much lower type than *Chara*, having a filamentous form. The vegetable origin of these pebbles would not be suspected, until one is broken open when recently taken from the water, when it is found to show a radiating structure of bluish green lines, the color indicating the presence of the plants, as it is characteristic of the group to which *Zonotrichia* belongs.

The relation of the deposits about Littlefield Lake to the direction of the prevailing strong winds of the region, is probably significant.

The area of deposition is at the southeast end and along the whole western side of the lake. The winds which would be most effective in the valley of the lake would be those from the north and northwest, which would drive the surface waters down the lake towards the southern end, and, striking the shore on the eastern side, currents formed thus would be turned across the lake to the west, depositing sediment at the turning area and in slack water beyond. The daughter lakes are not easily accounted for, except in a general way, that they were formerly deep bays, which, by the building out of points of marl on either side of their mouths, were finally enclosed. The tendency, already noted, for existing bays to have points of marl, of spit-form, extend from either side of the mouth would seem to indicate this as a probable method of formation. On the island at the south end of the lake there was manifestly a strong current, which was running southeasterly and depositing fine marl on the east side of the island, the wind at the time the observation was made, blowing gently from a few points north of west.

As has been already noted, the islands consist of marl from twenty-five to thirty feet deep, the bottom on which they are built up being, to judge from soundings, made with an iron rod, of rather fine sand. These foundations of sand have deeper water all around them, if soundings, said to have been made by local fishermen, can be relied upon, so it is possible they represent shallows in the original lake bottom, upon which after *Chara* had established itself, the marl accumulated, both by direct growth of the plants and by sedimentation. It may be worthy of mention, that the *Chara* growing on the steep banks, may in part, account for their steepness, by acting as holding agents, bind the particles of sediment in place by stems and the rootlike organs which the plant sends into the mud. It is probable that but a small part of the *Chara* that grows in the lake, ever reaches the shore wave line, and much must break up by the purely chemical processes, resulting from the organic decay in relatively deep water.

APPENDIX, ON THE SHELLS OF MARLS.

BY BRYANT WALKER.

Detroit, Michigan, Nov. 25th, 1901.

A. C. Lane, Esq., Lansing, Michigan:

My Dear Sir.—I enclose my report on the mollusks found in the seventeen lots of marl material received from yourself and Prof. Davis during the last two years. I have not included the recent species, of which several lots were received from Prof. Davis, as their determination was not particularly pertinent to the marl fauna. I can send you a list of them if you desire. There is, however, nothing of special interest in them and the list of Saginaw Valley shells, which you made use of in your former report,* will include them all.

Taken as a whole the fauna of the marl deposits does not differ from the present fauna of that portion of the State from which they come. Nor have I found in the specimens from any particular locality any special peculiarities, which would indicate peculiar local conditions of environment. Individual variations occur more or less frequently, but no more than is often found in similar collections of recent species. The inference is, therefore, that the marl fauna lived under substantially the same environmental conditions as the present fauna does or at least not sufficiently different to produce any special or characteristic variations.

The one species peculiar to the marl deposits of this State is *Pisidium contortum* Prime. It was originally described from the Post-glacial formation at Pittsfield, Mass. It occurs abundantly in the marl deposits both in Michigan and Maine. It has recently been found living in one locality in the latter State and it is quite possible that it may yet be found alive in this State. But so far as our present knowledge extends it is extinct in Michigan. Why this one species out of the fifteen, to say nothing of the other genera represented in the marl, included in our list, should have failed to survive, while all the others are still abundantly represented in our present fauna is very curious. I have been entirely unable to imagine any adequate explanation.

The characteristic feature of the marl fauna is the great relative abundance of certain of the smaller species. This is especially noticeable in *Planorbis parvus* Say, *Valvata tricarinata* Say and

*Vol. VII, Part III.

Amnicola limosa Say and *lustrica* Pils. The larger *Planorbis bicarinatus* Say and *campanulatus* Say occur in nearly every lot of material, but the number of individuals is comparatively small. *Pisidium* both in the number of species and individuals is also a characteristic feature of the marl as it is indeed of our present fauna. There is probably no district in the United States, in which this genus abounds to a greater extent, both in species and individuals than in the inland waters of this State.

The terrestrial species represented in the marl are few both in number and individuals. This is what would naturally be expected, as those that do occur are the occasional examples that have been washed into the water from the adjacent land. Such as have been found present no peculiarities as compared with recent specimens from the same region.

The almost complete absence of the *Unionidæ* from the collections is also noticeable.

The peculiar variations noted in *Valvata tricarinata* Say from Cement City are of considerable interest. A similar tendency to unusual variation, although in another direction, has been noticed in the same species from a Post-glacial deposit near Niles in this State (Nautilus XI, p. 121). In both instances, however, the variation was not common to the whole colony, but was limited to a very few individuals. It cannot therefore be attributed to any peculiar conditions in the environment for in that case it would undoubtedly be more general in effect.

Yours very truly,

(Signed) BRYANT WALKER.

N. B.—Please don't forget to give Dr. V. Sterki the credit for identifying the *Pupidæ* and *Pisidia*.

NOTES.

Numbers refer to numerals in table.

1. Fragment or fragments only.
2. Young shells, just hatched, undoubtedly recent.
3. Apparently recent.
4. Fragment, possibly *S. avara* Say.
5. Peculiar form.
6. Peculiar form, probably *L. humilis* Say.
7. Peculiar form.

8. Young.
9. Undoubtedly recent.
10. One left valve with teeth wholly reserved, one right valve with anterior laterals and cardinals reversed.
11. One valve with posterior laterals reversed.
12. Two samples with the apertural portion of the last whorl separated from the body whorl. One example with the superior and peripheral carinæ present, the umbilical carina wanting, its position however is represented by a slight angulation of the whorl. This remarkable variety has never been seen before among hundreds of examples examined. So far as I know there is no previous record of its occurrence. Should other examples be found it would be entitled to rank with the varieties already described. But as only single specimens from two different localities have been noticed it may be only an individual variation or "sport."
13. One example with the superior and peripheral carinæ present, basal one obsolete. See Note 12.
14. Deformed.

LOCALITIES.

1. Shell-bearing deposits in digging a well about 100 feet north-east of Sec. 36—13—5 E. A. C. Lane, Coll. No. 1.
2. Marl from A. F. Gorton. Lake near Howell. A. C. Lane, Coll. No. 2.
3. E. $\frac{1}{2}$ S. E. $\frac{1}{4}$ Sec. 3—11 N.—5 E. A. C. Lane, Coll. No. 3.
4. Cascade near Grand Rapids. A. C. Lane, Coll. No. 4.
5. Cedar Springs. A. C. Lane, Coll. No. 5.
6. Sec. 22, T. 10 N., R. 11 W. A. C. Lane, Coll. No. 9.
7. T. 11 N., R. 11 W. A. C. Lane, Coll. No. 10.
8. Pickerel Lake, Newaygo County. A. C. Lane, Coll. No. 11.
9. Indian Lake. A. C. Lane, Coll. No. 12.
10. Fremont Lake (12 N., 14 W.), Newaygo County, 150 to 200 feet above lake. A. C. Lane, Coll. No. 14.
11. Cut between Sec. 24 and 25, Spaulding Township, Saginaw County. A. C. Lane, Coll. No. 15.
This is a sand deposit of Lake Algonquin?
12. Marsh north side of Cedar Lake, Cedar Lake Station, Montcalm County. Lane and Davis, Coll.

13. Dry marl bed $\frac{1}{4}$ mile east of Cedar Lake Station, Montcalm County. Lane and Davis, Coll.
14. Marsh on east side of Mud Lake, N. W. $\frac{1}{4}$ S. W. $\frac{1}{4}$, Sec. 3, T. 12 N., R. 4 W. Lane and Davis, Coll.
15. From bank of ditch, N. W. $\frac{1}{4}$ S. W. $\frac{1}{4}$, Sec. 3, T. 12 N., R. 4 W. Gratiot County. Lane and Davis, Coll.
16. Bottom of ditch from Mud Lake. N. W. $\frac{1}{4}$ S. W. $\frac{1}{4}$, sand section, Gratiot County, "possibly washed from marl." Lane and Davis, Coll.
17. Goose Lake. Cement City. J. G. Dean.
This is the marl of the Peninsular P. C. Co.

LIST OF SPECIES—CONTINUED.

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
<i>Amnicola limosa</i> Say.....		x ¹		x	x	x		x ⁹		x	x			x		x	x
" <i>walkeri</i> Pls.....								x ⁹					x ⁹			x	x
<i>Paludestrina nickliniana</i> Lea.....											x ¹	x		x			
<i>Pleurocera</i> sp.....											x ¹	x					
<i>Gonitobasis livescens</i> Mke.....								x ¹									x ¹
Unionidae.....											x ¹						
<i>Unio</i> sp.....															x ²		
<i>Anodonta grandis</i> v. <i>footiana</i> Lea.....											x			x ¹		x	x
<i>Sphaerium simile</i> Say.....		x ⁹															
" <i>striatum</i> Lam.....				x		x ⁹											
" <i>rhomboides</i> Say.....																	
" <i>occidentale</i> Pme.....	x					x ⁹											
" sp.....						x ⁹											
<i>Calymene truncatum</i> Lind.....																	
" <i>securis</i> Pme.....		x ¹						x ²						x ¹			x
" sp.....																	
<i>Pisidium roperi</i> Sterki.....	x																
" <i>noyboracense</i> Pme.....	x	x ⁹														x ⁹	
" <i>affine</i> Sterki.....	x	x ⁹		x												x ⁹	
" <i>pauperculum</i> Sterki.....		x ⁹		x				x ¹¹								x ⁹	
" <i>variable</i> Pme.....		x ⁹		x												x ¹¹	
" <i>medianum</i> Sterki.....		x		x						x							
" <i>compressum</i> Pme.....				x						x							
" <i>scutellatum</i> Sterki.....																	
" <i>contortum</i> Pme.....																	
" <i>tenulissimum</i> Sterki.....																	
" <i>walker</i> Sterki.....			x								x ⁷						
" <i>peraltum</i> Sterki.....																	
" <i>strensi</i> Sterki.....																	
" <i>splendidulum</i> Sterki.....																	
" <i>roundatum</i> Pme.....														x ¹⁰			
" sp.....	x									x						x	

x Present.

x[?] Identification doubtful.

CHAPTER VI.

RECORD OF FIELD WORK BY D. J. HALE.

§ 1. Lansing—Summer, 1899.

Before starting on a longer tour of inspection a short trip was made from St. Joseph through White Pigeon, Bronson, Coldwater, Quincy, and several other towns near which marl had been reported. The surroundings of the marl, its location and manufacture and any other points needing investigation were to be noted.

White Pigeon.—The first bed visited was that of Mr. Theodore E. Clapp on Section 17, St. Joseph County, two miles southeast from White Pigeon, and one and a quarter miles from the Lake Shore & Michigan Southern railroad. The following are his figures on the bed. The depth is from six to thirty feet with average depth twenty feet, area 100 acres. The marl at the center of the lake is about twenty-two feet deep, at the edges thirty feet deep, water in shallows two to four feet in depth. The marsh land about the lake is underlain with the deepest marl, and this greatest depth is between the lobes of the lake. The marl is not overgrown sufficiently with marsh grass for cattle to graze upon it safely. For sounding the deposit he used two inch drive well pipe cut into six foot lengths, and fitted with couplings so that they could form a continuous rod. Upon one length an augur was welded. This was the apparatus used to bring up the specimens. Mr. Clapp made fifteen soundings, requiring a force of five men.

Tests were carried on during the winter through ice. The analysis of the marl made at Purdue University was as follows:

Moisture .....	.81%
Insoluble in Hydrochloric acid.....	1.46%
Silica .....	.37%
Iron and Alumina .....	.56%
Calcium oxide	51.00%
Magnesium oxide	1.02%
Potash .....	.17%
Soda .....	.52%
Carbonic Acid	41.10%
Organic matter combined with water.....	4.01%
Sulphuric acid	trace.
Phosphoric acid	trace.
<hr/>	
101.02	

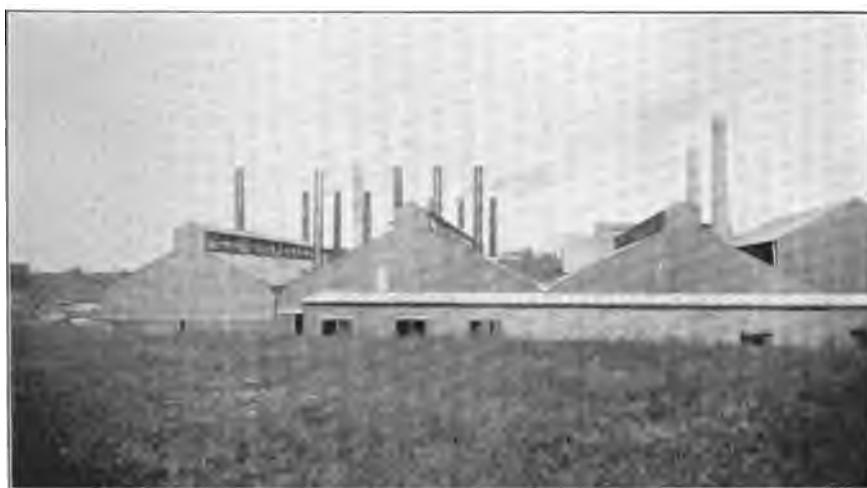
The above analysis would indicate a first class marl. The marl between the lobes of the lake, which was before remarked as deepest, in this instance probably marked the center of the lake. According to Mr. Clapp's soundings the deepest water did not contain the deepest marl, but rather the shallows at the edge of the lake toward the center of the whole lake basin. The lake basin would be the whole depression including the two lobes of the lake, and the low marsh surrounding it.

Bronson, Quincy, Coldwater.

After leaving this lake the old glacial valley or chain of marl lakes extending irregularly through Bronson, Quincy, and Coldwater was examined. It was near Bronson, while sinking piles for a bridge over a creek that a section foreman discovered a marl bed. The whitish or greyish soft mud which he found there, proved upon analysis to be a marl suitable for cement. A thriving factory was started upon this same land, also one at Union City some fourteen miles distant. One is built at Coldwater and another completed at Quincy, these two belonging to the Michigan Portland Cement Co. This constituted the district which was at the time (1899) actively devoted to the manufacture of marl, although factories were in the process of building in many parts of the State.

The bed and factory at Bronson were first examined. The factory itself is located on a sandy island a few acres in extent. These islands are sprinkled through the marl bed, and upon some of them good sized trees are growing. The deposit is one of the old lake valleys above mentioned. In reply to questions asked Mr. Wheeler, the chemist of the factory, the following facts were given. The area of marl is estimated at 1,300 acres. It follows the bed of Swan Creek, and two or three other streams from Spring Lake. The depth varies from one to fifty feet according to measurements made with solid iron rods. Beneath the marl there is a white quartz sand, the outline of which is regularly undulating, which Mr. Wheeler accounts for by the former action of waves. The marl is about thirty to forty per cent water. The lake basin is in the form of an oblong one mile wide and several miles long.

The factory contains seven rotaries and six tanks with an output of 1,000 barrels per day. The occurrence of marl under one part of the marsh does not signify that it will be found under the whole marsh. The bed is thickest at the center. It contains no bog iron ore,



COLDWATER PLANT OF WOLVERTON P. C. CO.



UNION CITY PLANT OF PEERLESS P. C. CO.

and few shells. The well water in the vicinity is rather soft. His analysis of the marl is as follows:

Volatile matter	45.64%
Insoluble matter	1.72%
Iron and aluminum oxides.....	1.17%
Calcium oxide	49.21%
Organic matter	7.07%
	<hr/>
	104.81

Further analyses and descriptive notes will be found in the last chapter.

The marl is dug by an ordinary dipper dredge which scoops out the marl to a depth of twenty-two feet and empties it into small cars in which it is hauled to the factory. The dredge first removes the surface from one to six feet of tough marsh grass, roots, etc., and piles it up at one side or dumps it in place where the marl has already been removed. As the water stands at within from one to two feet of the surface, after a small channel is cleared the dredge has water room to float over the marl which is to be removed. The marl when first dug is much darker on account of being nearly half moisture, but after drying, it becomes about the color of light wood ashes. The next point of interest visited was the clay pit from which the supply of clay for this factory is derived. The pit is on a siding about two miles south of the factory. It is in this vicinity that the great stratum of Coldwater shales is uncovered. In this case the shale does not quite reach the surface, and a shaft seventy-five feet deep has been sunk to penetrate the surface soil, and from the vertical shaft a tunnel with several smaller branches has been dug through the solid shale. A regular mining hoist is used to reach shale and hoist it to the surface. Clay is transferred from the head of the tunnel to the shaft by small cars run on a wooden track. The clay, which is a shale compressed until it shows lines of cleavage, is hard like a rock and is blasted by giant powder as coal is mined.*

The next point visited was Coldwater. Between Bronson and this city the land is rolling and very stony. It does not present the sudden contrast in outlines which characterizes the marl regions further north.

The Coldwater mill is located near several small lakes. The manager of the works who was present during the prospecting

*For analysis see Part I, p. 41 (Clays and Shales by H. Ries).
14-Pt. III

could not see that there was any regularity in the depth of marl. It showed no greater thickness in the center. The soundings were a succession of sudden changes in depth. Compare the soundings at the lower end of Long Lake in the Cloverdale region. It must be remembered that these lakes were lined with clear marl at the bottom as at Cloverdale and not a completely leveled marsh filled in with vegetation as at Bronson. It is well to notice how the different lakes compare with swamps in increase of depth toward the center of the marl deposit. The marl lands at this point available for cement manufacture were said to aggregate two thousand acres. The beds in this chain of lakes are to be worked by two fourteen-rotary mills, one at Coldwater, and the other at Quincy.

The clay used at Coldwater differed somewhat in appearance from that used at Bronson. It is a surface clay mixed blue and grey in color. Its advantage lies in its easy access and cheap grinding.

Jonesville.

At Jonesville, Mr. Chase Wade was interviewed. A factory was completed at this point. The bed to be utilized has an area of from seventy-five to eighty acres with an average depth of twenty-five feet. The analysis showed from ninety-three to ninety-five per cent of calcium carbonate.*

Kalamazoo.

The return trip from Lansing to St. Joseph was made by way of Hastings and Kalamazoo. At the town of Cloverdale the Chicago, Kalamazoo & Saginaw railroad passes through a cluster of lakes, and on account of the promising outlook it was deemed advisable to make a thorough investigation later, the result of which is given in the description of the Cloverdale district.

Kalamazoo was next visited, and the site of the former cement plant was examined. A chain of three small lakes form a deep valley with a rate of fall so great that a small water flume bringing water about a half a mile from the creek at the headwaters of the lake furnished ample water power for a large mill. The lower of the three lakes was nearly dry and the marl exposed was very light colored with many shells. In this lake there was little or no surface muck. In the upper, however, the depth of marsh surface was

*See report by W. M. Gregory, upon the plant of the Omega P. C. Co.

so great as to render the marl scarcely available for manufacturing purposes. One of the first factories started in the State was built on this marl bed, but with the old kiln process and with the expensive method of handling raw materials, it did not pay.*

The next marl bed reported was in the vicinity of Niles. It was five and a half miles east of the town, and covered about forty acres. Deep wells in the vicinity were said to have very hard water, and the hills surrounding terminated abruptly at the edge of the marsh and were of gravel.

§ 2. Cloverdale.

The peculiar formation of the region about Cloverdale makes a very interesting locality for the study of the formation and occurrence of marls. By consulting a map of Michigan it is seen that the townships of Hope, Barry, and Prairieville of Barry County contain an unusually large number of inland waterways and lakes. (Fig. 3.) The country is a network of deep depressions forming dry channels, gullies, water courses and lake beds. Between channels are high gravel and clay hills. The soil is very heavy but forms a greatly varying mixture. At one place it may be a tough till of clay, gravel and boulders which may be traced a short distance and then may be replaced by fine sand, clay or gravel. A cross section of the land as seen in cuts in side hills, washouts or wells shows as much if not more variation. The bottoms of gullies and kettles left by the receding water generally have a blue, black or red clay bottom hidden by a few inches to as many feet of loam or sand. These dense clays formed the bottoms of numerous lakes and channels, many of which have dried out with the fall of water level, but the largest and deepest of which form the present lakes of the township above mentioned. Within a radius of three or four miles of Cloverdale, Hope Township, on the C. K. & S. there are five lakes and several other holes not entirely dry, a fair sample of the latter class being "Twenty-one Lake" west of Cloverdale. The five lakes examined, all of which contained marl, were Long, Round, Balken or Horseshoe, Guernsey and Pine.

The purpose of the investigation was to study the mode of formation, extent and quality of the marls and clay in and about the lakes, so as to ascertain if possible their origin and their adaptability to cement manufacture. As the marl is supposed to originate

*The quality was very good, as is shown in many places in Kalamazoo, where 20 years has made little impression on the cement. L.

in one of several possible ways from the salts contained in underground waters, the relative hardness of spring and well waters surrounding the lake to the hardness of the surface of the lake and its deep water together with its outlet, was determined. This required the collection of samples of water in small fruit jars, which after filling were shipped to the Michigan Agricultural College for analyses. On page 46 will be found a table and key to analyses with a brief enumeration of results obtained. The surroundings of the beds themselves, the nature of the soil, and general impressions as to the formation of the whole lake may throw light upon the changes which may have brought about these curious deposits. These were therefore noted where possible and the conclusions drawn from these facts have been noted in Chapter IV.

To determine depth and outline of marl beds and to obtain samples at any depth the following apparatus was made. It consisted of fifty-four feet of inch pipe (three 18-foot lengths each cut in two making six pieces each nine feet long). Each piece was threaded on both ends and when a coupling had been screwed upon one end of each pipe the whole could be united into a continuous tube fifty-four feet long.

Fifty-four feet of one-half inch pipe was cut, threaded and coupled as above except that the couplings were turned down slightly in a lathe so that when coupled with the half inch pipe, they would allow it to pass freely within the inch pipe. Two shorter pieces (each four feet) of one-half inch pipe were provided, threaded as the others, but each shod to suit solidity of the material to be penetrated. The lake bottoms investigated in this region varied from a fine almost impalpable mud suspended in very deep water to very sandy or very dense clay carbonate. The very sandy and very muddy bottom would be washed off the worm of an ordinary augur. To obviate this difficulty and to preserve the specimens while being hauled to the surface, one of the short pipes was shod with a device which is somewhat of a miniature of a well driver's sand pump. It consists of a cylinder of iron just the diameter of a half inch coupling hollowed out and chisel pointed. Upon one side of the chisel surface a hole is drilled up the center to the hollow, which hollow is the exact size of the inside diameter of the one-half inch pipe. The hole is stopped on the inside by a ball valve, the ball being retained within the cylinder by a wire passing through the cylinder at right angles to its length three-

eights of an inch from the bottom of the hollow. A thread is cut on the inside of the upper end of the cylinder making the end with threading just the size of a half inch pipe when threaded. It must, therefore, screw inside a coupling which joins it to the short piece of the pipe. When chugged down the valve allows the soft mud to spurt up into the cavity but when lifted the ball drops down into the hole drilled through the bottom, stopping the egress of the contents through the hole by which it entered. At each fresh downward thrust of the chisel the content of the cylinder increases, rising in the hollow half inch cylinder to the top where elbow or one-way coupling may be screwed on to direct the outflow which may be received for examination.

The other short pipe was shod with an augur, the worm of which was similar to a ship augur, but the stock of which was hollow so as to allow whatever ascended through the worm to pass up into the half inch pipe as in the previous case. When the marl was somewhat solid as was the case when the chisel was used, an iron poker one-fourth inch in diameter was used to shove the specimens out of the pipes. These are the only means so far seen which serve to bring to the surface a correct specimen of lake bottom from any depth. Specimens of lake marl were brought to the surface from beneath several feet of mud and fifty feet of water. The outer pipe serves solely as a protection and support to the inner pipe which is liable to break loose from the couplings when forced to great depths. This outfit while absolutely necessary for scientific research was not used by me in later soundings. Where the marl becomes nearly as dense as a limestone, as in the several instances in the Northern Peninsula, the chisel of the sand pump with a double tube, the outer being shoved down as the inner cuts its way through, is the best outfit that can be used. But as the marl in two-thirds of the cases seen lies on top about like "butter in summer," and at the bottom like "butter in winter," an ordinary $1\frac{1}{2}$ inch augur welded on to $\frac{1}{2}$ inch pipe will retain the marl and stand the strain necessary for numberless soundings. If one man is sounding alone he may use $\frac{3}{8}$ inch or $\frac{1}{4}$ inch pipe, but is liable to bury the lower half of his rod out of reach in some marl bed.

With the outfit first described, which was fitted up in half a day at a machine shop in Kalamazoo, five lakes were examined in five days with a crew of four section men. A raft was made by slightly fastening two boats together with a framework of boards, the two

heaviest boards lying parallel to each other across the boat amidship. These furnished a footing and prevented the tip of the boats from pressure of lifting on their inner gunwhales.

Four men rigged a boat raft from a pair of boats and old lumber in about half an hour. They then rowed to any desired position, anchored at bow and stern and made soundings. Specimens were generally taken from bottom and surface of the marl bed at the same spot. Boats and men were then taken to the next lake by team, about a day's work being expended on each lake.

The first lake examined was Long Lake (Fig. 3, p. 14). It is about three and one-half miles long and very narrow, being nearly cut in two by Ackers Point. The C. K. & S. R. R. runs parallel to it and bounds it nearly the whole length on the southeast side. The town of Cloverdale lies nearly all south of the railroad and at the southwest corner of the lake.

The surroundings of the lake are worthy of notice as perhaps having a remote bearing upon the origin of the lake and its contents. The southwest or upper end of the lake is bounded by an abrupt hill or bluff about seventy-five feet high, consisting of a dense till or mixture of tough clay, gravel, and boulders, and crowned by hard wood timber. This hill is flanked upon the south by lower land than on the north, the only land touching the lake being a heavy blue clay, which has flowing beneath it several springs. That on the south forms a narrow isthmus between Long Lake and Round Lake lying to the southwest. A canal or ditch had at one time been dug through this neck of land to a distance of two to three hundred feet, and the fall of water from Round into Long Lake was 16 feet, furnishing water to drive a mill. The surface of the neck of land, beneath which is clay and quicksand, is sand. The banks of Long Lake are flanked on the northwest and southeast sides by high, rolling, gravelly clay hills, which end abruptly at the shore and through which several cuts have been made by the railroad.

The lake rapidly narrows at the northeast, and to its outlet, which is a small creek flowing through a narrow low land into other holes which have once been lakes but could not be reached in any way with sounding apparatus. When the water was higher the whole must have looked like a large river without low lands, with little current, and abrupt shores.

The first sounding was made in the narrow channel connecting

the two halves of the lake at Ackers Point. From here soundings were made at short intervals circling the shore to the right and south side toward the outlet, from thence returning on the west side to place of beginning, and from there on the north side of upper half around the upper end past Cloverdale, and back on south side to place of beginning.

The bottom immediately about Ackers Point was of heavy sand and gravel for some little distance out, probably having been washed down from the point over the bed. The first sounding, 40 feet out from heavy gravel shallows, showed a depth of 30 feet of marl, and at the bottom a fairly solid tamarack log, sample of which was bored and torn out, being brought to the surface by the augur.

See pages 18 to 21 for a list of soundings taken, showing depth of water, depth of marl, nature of bottom and analysis number where a sample was preserved for analysis. This number, upon reference to the accompanying table of analysis, will give the chemical constituents of the sample as far as determined.

The sounding No. 1 at Ackers Point was one of the deepest made and the sample taken was among the purest. As the lake widens from the narrows the shallows spread out and divide, following the north and south shores. The shallows extend out from the lowlands on shore perhaps 200 feet, gradually deepening, when there is a sudden jump into deep water, making a shelf much like a sand bar in a river, but not to be expected in a lake. Where opportunity offered, soundings were made on the edge of the shelf and in the deep water outside to determine exactly what was the relationship of depth of water, marl, bottom and true bottom. For the sake of clearness this relationship is pictured crudely by diagrams, which will be referred to by numbers.

Diagram 1, Plate I, shows the shelf as found by soundings Nos. 8 and 10. It will here be seen that the fall of level of the true bottom is more gradual than that of the marl or false bottom as the layer of marl decreases 10 feet. It is not well to form an opinion upon this one relationship, but to watch if it holds true in further comparisons. It is also noticeable that samples 3A and 3B, or specimens taken from Nos. 8 and 9 on the shelf show more sand than No. 10(4) taken off in deep water. This comparison was made about half way down the lower lobe of the lake. The shallows finally again covered the bottom and joined, making an extensive flat which

continued to the outlet. At the head of this flat, and about the center of the lake, was the next object of interest. This was a rocky islet about 40 feet long and 10 feet wide, formerly a cigar-shaped, stony shallow along the center of the lake. The largest boulders are just above water. All are covered with a thick, very soft, white coating of lime, which is fastened to glacial pebbles, covering them all much like a snow storm, i. e., thickest on top and scarcely at all upon the under side, though the stone may be free from others and exposed to the water. The white coating of lime hardens quickly when exposed and dried in air. A cross section shows two layers of granular friable lime, between which is a layer of green organic matter or chlorophyl revealing the presence of living organisms.

Soundings 13 and 21 were made in the mid channel, 13 to the south and 21 to the north of the island, showing conditions on each side of it. With the depth of water the depth of marl is, respectively, 9 and 23 feet, showing that the north channel was originally much deeper, the marl now filling both and making them very shallow.

The conditions thus shown immediately at the beginning of the large shallows at the foot of the lake are interesting. A rocky islet just reaches the surface of the water. From this islet the depth of marl increases from a coating a fraction of an inch thick to 23 feet thick on the north, 9 feet thick on the south, with a shallow channel 4 feet of water. Soundings Nos. 12 to 14 show the conditions in a line down the lake, 12 before the island is reached, 14 after passing around the island in a line toward the outlet. These soundings show again that the island is surrounded in two other directions by 12 and 33 feet of marl. The increase is not, as the soundings would indicate, sudden, but gradual, the island seeming like a bouldery outcrop of the bottom, which is at No. 12 heavy gravel, at the island bouldery, and at No. 3 at 33 again fine lake sand.

Taken as a whole, soundings 12-22, inclusive, show somewhat the shape of the lake bottom under the shallows to the foot of the lake and as far into its outlet as the raft could be propelled. In no case is the water over 6 feet deep, except in the swimming hole near the north bank. Soundings 14 and 17, taken in nearly a straight line, show a deep channel which narrows and runs into the shallow outlet. No. 16, taken to the north and left of these, shows but a trace of sandy marl with a gravelly bottom. No. 16 is more

notable, as it was taken from the foot of a hill from which several springs issue. Prodding 50 feet to the south of 16 shows about the same condition, proving that the bed rapidly narrows, but the sudden jump downward in No. 17 shows that the outlet still remains the old channel, though nearly choked up with marl, with no surface muck. Proddings not recorded as soundings show that southwest of sounding 16, returning to Ackers Point along the north side of the lake, the muck and gravel from steep hills encroach upon the bed. The sudden contrast in the nature of the bottom is shown by comparing sample 6 of table, which is a muck from the narrowest outlet, with Nos. 5A and 5B, fair samples of marl in deep or old channel.

Nos. 21 and 22 (Plate I) are again parallel to Nos. 8 and 10. No. 21, the same referred to as north of Rocky Island, was taken just outside the swimming hole. Diagram 2 shows the relative change in depths of water, marl and true bottom. Here the relation in fall of marl and true bottom is exactly reversed as compared with Diagram 1. The marl bottom or shelf is less pronounced than the original shelf made by the true bottom before marl was deposited because the marl bottom is like a thick bottom before marl was deposited, is like a thick blanket taking away the sharpness of the edge and by its own increase in thickness of 8 feet, making the fall less sudden and the lake bottom more nearly level. Still the increase of water from 4 to 16 feet is so immediate that outline of the white bottom seems to sink suddenly out of sight. The original bottom with an almost immediate fall of (47-23) 24 feet must once have formed a bold precipitous terrace or more likely in this case a small deep kettle.

By the above soundings, together with many proddings and examination of bottom in shallow water by the eye, the following general idea of the broad shallows at the foot of the lake and merging into its outlet is given: The bottom of the deep mid lake suddenly rises to form an extensive shallow. It even shows above the water's surface in the stony islet, but slopes down on either side of the islet to form deep channels, the one on the north being deeper (27 ft.), the one on the south 13 feet. The bottom is somewhat uneven and pebbly where it is shallow. On the other hand there are many holes, the largest of which, the swimming hole, is 47 feet deep below water with the bottom surrounding it 27 feet. Besides holes there is a deep middle channel north of the stony

islet and running into the outlet. The bottom rises on each side to a pebbly shore covered toward the outlet with muck or sandy marl in very thin layers.

The shore on the north side has the steep hills and springs back of it. The marl lies upon this original bottom covering it, nearly filling up the old channel and hiding all but the deepest hole, which it helps to fill. It, however, forms but a thin incrustation on the rocky islet, but in the channel thickens again to natural depth. It merges into sand and mucky marl (Analysis No. 6) toward shore, but shows admixture of sand even in the deep channel.

Upon continuing up the lake on the north side, leaving the broad shoal, a layer of sand is found between Nos. 22 and 23. But the shoaling marl again thickens on approaching Ackers Point on north side, showing no unusual features excepting that it can be easily seen that the old channel past Ackers Point has been filled to a depth of 30 feet with marl like the channel described leading out of the lake, and also that the marl is much thicker immediately in the narrows and about the point than along the shore down the lake.

From the point opposite Cloverdale the lake widens with a slight bend reaching out to the north toward the only low land. No. 27 was taken to find if the depth were any greater below the springs which emerge from the heavy clay lowland at the north corner of the lake, but no great difference in depth between that and many other soundings taken in the absence of the springs could be noted. The depth and quality of marl here are just the opposite to sounding 16 at the foot of the lake. In this case a fairly deep layer (25 ft.) of marl, with fine sand bottom, was found, while No. 16 showed 2 feet of sandy marl with gravel bottom.

At the foot of the steep till bluff before referred to as forming the boundary of the head of the lake there was a boxed spring (Sample 1, p. 46, taken here). Below this spring the water was shallow and appeared to be a sand bar, but upon investigation from boat with sounding apparatus the marl was found to run almost up to the bluff at a good depth, but the sand has washed over it to such a depth that it was reached with difficulty by the pipes. In coming down the northwest shore, which was described as mostly sand in places where marl was struck, it was found that the marl was interlayered with sand, the augur first sinking through soft marl, then grinding in sand. This would seem to point toward a washing

action of the sand over the marl during the period of deposit of the marl. Nos. 28 and 29 (Diagram 3, Fig. 4) were another parallel set (Plate I), showing the position of the marl overlying the shelf, being made close to shore under the bluff and in shoal water. The soundings were taken as closely as possible to each other and the changes in depth are very sudden. The marl layer again tends to break the abruptness of the descent of the true bottom. The difference in depth of water on and off the shelf being greatest before the deposit of marl, for before deposit the shelf was 24 feet high, after deposit 15.*

Another test opposite Beechwood Point, a short distance below Cloverdale, showed the gradual increase in depth of marl, from deep shoal water in as far as possible toward Beechwood Point, at

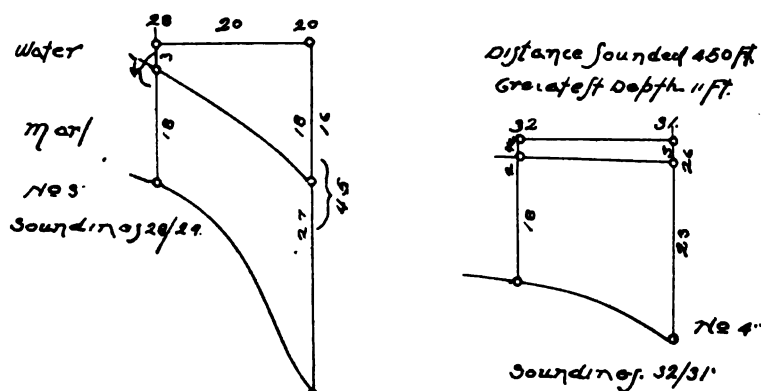


Fig. 4. Diagrams 3 and 4, of soundings 28, 29, 31, 32, Long Lake.

right angles to the length of the lake. In 50 feet the increase of depth of marl is 5 feet to an increase in depth of water of 1 foot (see Fig. 4, Soundings 31 and 32).

The general idea of the lake as given by the foregoing examination is that of a very long, narrow body of water. It consists of two quite distinct parts, the deep water and the surrounding extensive terrace or bar. Over the whole the marl lies as a thick and more or less even deposit which thins toward the shore edges where it is pretty thoroughly mixed with sand, clay or muck. The sudden changes in thickness of the marl layer seem due in greater part to the inequalities in the bottom, which is full of jogs, channels and holes. In all cases excepting Diagram I, the marl in cover-

* (45-21) instead of (18-3), see Fig. 4.

ing the terrace or shelf made by the bottom always lessens its very abrupt descent, being thicker just outside the shelf in deep water than in the shoal water upon the shelf. In this lake variation in the composition of the marl is very marked. In close proximity to the shore the marl is quite thoroughly mixed with sand. This condition extends out one or two hundred feet, as in samples from Sounding 8. Other instances before alluded to show the marl to be layered with sand and next to the very steep hill at the southwest end the sand has washed completely over, hiding the marl.

In this lake the marl layer seems to lie heaviest on the south side of the lake. It covers the whole lake bed, including the bottom 45 feet deep at the center, but lies heaviest over the terrace on the south side and has choked and completely filled holes and channels as deep as the mid lake 47 feet (Diag. 2, Plate I). Compare with sounding 10 mid lake, also No. 14 deep channel. A comparison of their soundings shows the former capacity of the lake. On account of the repeated admixtures of sand and muck the duplicate analyses furnish little data for consideration of difference in depth excepting in the deepest sounding, as 1A and B, 2A and B, 3A and B. These, the most nearly pure samples taken show, if anything, an increase of organic matter with increase of depth. There is no doubt that within a short distance of the bottom sand has worked up into the bed so that a sample, though taken with the greatest care, will show high in sand when taken within two or three feet of the true bottom. Here as in nearly all soundings taken during my experience the deeper soundings and the surface samples differ considerably in appearance, the deeper being fine grained, compact and of a steel-blue tinge, which with a high per cent of organic matter, becomes darker.* The surface samples were generally whiter, more flaky in appearance and lighter. No. 4 (Sounding 10) is of interest on account of its position 45 feet below the surface in Mud Lake. Like the other deep soundings it is high in "organic matter" and matter insoluble in HCl. No. 6 is a fair example of the mucky marl of the lake, little of which was found and that at the narrowed outlet. Notice the increase in organic matter and insolubles which far exceeds all but 3B, which was mostly sand. With this increase of organic matter there is an increase of iron and aluminum as there

See pp. 16 and 18.

is also in No. 4, the mid lake sounding. This is natural, as organic matter is supposed to aid in the deposit of iron.

All in all, sand and organic matter have penetrated this bed from beneath and from the edges. Only in mid lake in the thickest part of the deposit for some distance from the surface down is the marl free from foreign matter. The bold shores and the manner in which the sand is found constantly washed over and against the beds are perhaps good explanations of this condition.

Organic matter as a constituent of the marl is found in largest percentages in the bottom of the deepest parts of the lake.

Mud or Round Lake, as before described, lies southwest of Long Lake, the two being separated by the high clay and gravel hill. This lake continues southwest, paralleling the railroad for a short distance, then winding to the north. The lobe at Cloverdale and nearest Long Lake was examined for marl. The water of its outlet could not be sampled as it was at the other end of the lake, its waters emptying in a nearly opposite direction from those of Long Lake, the hill forming a divide. The hardness of the water as compared with Long Lake, was as 1 to 16, being nearly as soft as rain water. The bottom was heavy gravel or muck with finer sand. Of all the soundings made but one revealed the presence of marl. This marl of poor quality was found 38 feet below surface beneath several feet of silt and by the deepest sounding made in the lake.

Standing at the divide between the lakes the general contour of the bluffs or shores of the two lakes would show Mud Lake to be much higher, about 15 feet according to the fall of water at the mill. The hills about it are not as bold and upon the whole its waters do not so deeply indent the surface of the country. The springs which do not flow from the hills slip out at the shore line, are softer and probably are not from as low a level as those of Long Lake, being mostly surface drainage.

The wells in Cloverdale and those near the two lakes and on the divide were tested. The deep drive wells of Cloverdale were of the hardest water found. The deeper one on the divide was hard, the surface one soft.

As the people's idea of hardness and softness of waters in a given vicinity are very conflicting some method was sought to obtain a definite comparison of waters upon the field.

A standardized soap solution was made in the laboratory by titrating a known volume against a known weight of crystalized

CaCO_3 , or marble, so that every cubic centimeter of the solution needed to make a suds with 50 cc. of water, would imply one degree of hardness,—one grain per U. S. gallon of calcium carbonate or its equivalent.

The soap solution was carried in the field and measured against 50 cc. of spring or well water tested. The figures below, opposite the well or spring located, are the number of cc. of the solution required to neutralize 50 cc. of the water and form a comparative test of the hardness of the water in question:

1. Well, Hotel at Cloverdale.....	20.00
2. Water of Mud Lake	1.00?
3. Water of Long Lake	16.00
4. Deep well on divide between lakes	16.6
5. Ludwigs (box spring at foot of hill)	12.2
6. J. L. Chamberlain's well west of hotel	16.6
7. Simon Dayton shallower well on divide....	8.0
8. Deep drive well Southwestern Michigan....	13.

From this it will be seen that the lakes contrast sharply. The deep wells (Nos. 1 and 6) are hard, shallow wells on divide, No. 7 medium, and Mud Lake very soft.

No. 5, the deep spring, is quite hard.

No. 8, from non-marl region, is softer than deep well waters of this locality.

In comparison the waters of the two lakes form a sharp contrast. It is the settled idea in this part of the country that a hard water lake means marl and a soft water lake the absence of it. Several instances besides this under my direct observation were given me and I have never in my own experience found a lake which tested very soft water to show anything but traces of marl.*

In the case in question Mud Lake is not cut so deeply into the glacial drift as Long Lake. While there is sand and gravel on the edges, deeper there is a clay hard-pan, while Long Lake is in fine sand bottom. On the divide between the two in the wells driven there is said to be a heavy clay layer. Under these circumstances the only explanation to be seen is that Round Lake receives the surface drainage of soft water and is withheld from seepage into Long Lake by a clay hard-pan. Long Lake cuts deeper into the drift and receives the hard water springs and drainage from the same layer as the deeper wells.

*See analysis of Goose Lake water, of Peninsular P. C. Plant.

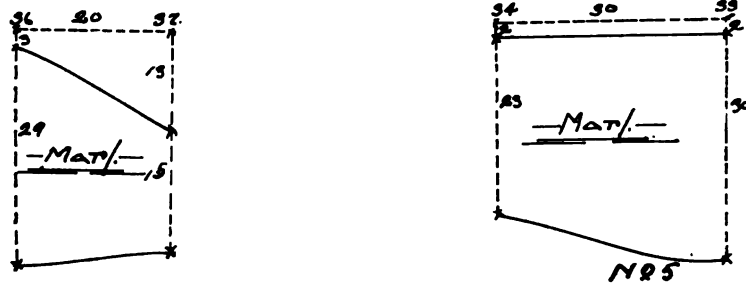
The next lake tested (Pl. II) was Balker or Horseshoe Lake. It lies about two miles east of Cloverdale and a mile in direct line at right angles to the C. K. & S. in the N. E. $\frac{1}{4}$ of Sec. 22 of Hope Township. It draws one of its names from its shape. It has two lobes or arms and a basin into which both empty and from which issue its outlet. All the attention was devoted to the south lobe and basin as a raft and tools could not be propelled into the north arm on account of the shallowness of the channel which was filled with marl, covered with a few inches of water. The two arms, like the sides of a horseshoe, are surrounded by a low marsh covered with tamarack, a good part of which must have recently been covered with water as it is but little higher than the lake surface. The south arm as it now exists is nearly round or elliptical in form. The east end consists of a large and very shallow flat upon which the first soundings were made. This flat leads into the basin by a narrows almost choked with marl. Here it is well to remark that the marsh vegetation characteristic of marl flats in general is a long cylindrical reed without leaves or branch, which shoots up many feet from a marl bottom or grows in very shallow water, as in this case, where it almost blocks passage of a boat. It is true that this reed* is found to greater or less degree on sandy or mucky bottoms, but it is one of the few practical guides to the location of marl, though like all others never entirely trustworthy.

Except for the shallow flat mentioned the rest of the lake has the shelf-like bottom already noted, the shallows forming a ring but 20 or 30 feet wide about the abrupt descent into deep water. Soundings were made on the edge of the shallows and across the lake from two sight points to determine if possible the profile of the bed or its cross section as cut across the lake. Before describing the various soundings it will be well to notice that the lake proper, which so far as determined is underlaid with a deep deposit of marl does not cover anywhere near all the depression lying between the steep bluffs. The lake as a whole more deeply indents the surface of the country than does Long Lake. The bluffs are steeper and more abrupt, the springs are noticeably larger and more numerous especially near the lake proper, which lies horseshoe shaped, curving around the south and west side of the valley, the remainder of which is covered with low tamarack marsh. The springs are also of harder water.

**Scirpus lacustris*? L.

The soundings were begun at the approach to the narrows in the south arm. The bottom as at Ackers Point, Long Lake, rises at the mouth of the narrows into a flat shallows. Soundings 33 and 34 (Diag. No. 5) were taken approaching from the center of the lake toward the shallowest place in the narrows leading into the basin. The distance between soundings is about 50 feet, and while the depth of water remains the same, original bottom sinks 7 feet, i. e., the depth of marl increases that much. The real bottom of the lake is the opposite in incline to false bottom. This is paralleled in Long Lake where the narrows at Ackers Point, though choked with marl, were nearly as deep as the remainder of the lake, as the false bottom has a gradual incline, not terraced like the sides, but built up by marl. This is true in the east shallows of the lake, but not true of terraces on north shore. (See Diagram No. 6.)

The next surprise is the relation of 36 and 37. No 36 is taken on the usual terrace and 37 just outside (see for slopes of bottom



No. 6.

Fig. 5. Soundings 33, 34, 36 and 37, Horseshoe Lake, T. 2 N., R. 9 W.

Diagram No. 6). Here the depth of original bottom is less by 3 feet toward the center of the lake than on the shore terrace. As this shore was lined with marsh it is hardly possible that the marl extends in a perpendicular bank against an opposite solid bank or shore, but in all probability the marl layer extends out a great distance under the marsh. This could not be determined, but this must be inferred from a comparison of the soundings of the other terraces before made. I know of no possible explanation of the almost immediate drop of level (29-15), 14 feet in thickness of marl bed unless currents of long ago where different water level and direction of drainage may have cut marl out in some places and filled in others. (See Fig. 5, Diag. No. 6.) From this short point, upon which No. 36 was taken, the line of the soundings was continued.

straight across a slight neck in the lake to the neighborhood of springs on slightly higher ground. No. 38 showed increase in depth of marl again. At No. 39 a sample of water was taken by lowering a corked jug to the bottom, pulling the string allowing it to fill and at once raising to the surface and putting the water into the fruit jar which was sealed as usual. (Analysis 5, page 46.)

No. 40, the deepest sounding anywhere made, was interesting both from what it revealed and left buried in obscurity. All the pipe in the apparatus was used without touching the original fine sand bottom of the lake. At the depth of 60 feet the sample which was almost fluid was retained by the sand pump and is shown in Analysis 9 of the table on p. 20. This analysis shows the highest per cent of Fe_2O_3 and organic matter of any taken in the lakes. There was no clay and comparatively little sand as shown by the low per cent insoluble. It is also lacking in MgCO_3 , showing a decidedly lower per cent than the rest of Horseshoe Lake. This, as

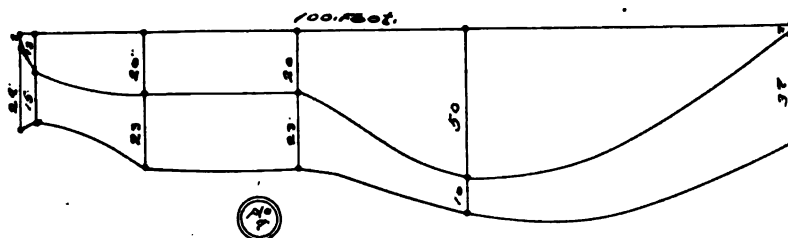


Fig. 6. Section showing Soundings 36, 37, 38, 39, 40 and 42 of Horseshoe Lake.

may be noticed in later soundings, is not the only lake in which the marl of the deeper portions gains greatly in organic matter. But such an increase in iron has not been elsewhere noticed.

Sounding 41 was a little to the east of the foregoing series, at the mouth of a very large spring. This spring emptied from beneath a bank at some distance back from the water's edge and by a small rill into the lake. The boats were shoved in as far as possible and a sounding taken in a few inches of water. The pipes sank with little effort to a depth of 32 feet. The sample from the very bottom was like that at the top, a fine silt with a trifle of lime which could be faintly detected by acid. The spring formed a large reservoir 8 feet across and 5 feet deep. At the bottom was its fountain a foot across and boiling up through black silt. The analysis of this sample of water is No. 4 of page 46. The peculiar phenomenon here witnessed was that one of the largest and hard-

est springs should show no trace of marl immediately in or at its outlet.

But next comes Sounding 42, made perhaps 50 feet to the west and completing the outline series, the whole of which are set forth, making a cross section of the lake bottom as shown in Fig. 6. Sounding 42, but a short distance from the spring and within 25 feet of solid ground, a bank about 15 feet high, showed marl to 37 feet depth, the deepest sounding anywhere on the lakes.

And here it is well to remark that Horseshoe or Balker Lake had the uniformly thickest layering of marl of any of the five. It in fact was so thick that its nature was difficult to discover on account of the slowness and labor in making deep soundings. Whatever the agents were by which such a bed was laid down they should be apparent in so thick a bed. The springs were large and their water hard, but no visible connection between the water of the springs and the marl of the lake could be discovered. The largest spring and its immediate vicinity were free from all but traces of lime. A very deep layering, about same depth as marl, of silt replaced the marl in and about the spring and at its outlet. The interesting phenomena apparent on the Rock Islet in Long Lake, namely the thick lime coating of the pebbles, was again manifested in a part of the lake at the shallows at the foot of the lake next to the narrows leading into the basin. This shallow area covered several acres and was from 1 to 2 feet in depth. The marl layer as shown by the first two soundings varied from the center in toward the narrows from 23 to 30 feet in depth. In an ordinary marsh, especially in the reeds or rushes, the bottom is black or dark-brown from dead rush, twigs, silt, and other marsh accumulations, but the bottom here, even in the reeds which ought to catch and hold everything that came to them, was gleaming white marl. In fact it was very much lighter in color than the specimens at the bottom which were in almost every case steel-blue in color. This color with a lack of a trace of organic matter at the surface was in this particular case perhaps explained by a more minute examination of the bottom. A branch of a dead tree leaned over and where it touched the water disappeared from sight. Upon following it beneath the water's surface it was found to have become coated with white lime covering, essentially the same in structure and appearance as that of the pebbles in Long Lake. There was the same triple coating of green or chlorophyl between the layers

of granular lime. In the distribution the lime reminded one of the limbs of a tree after a snowstorm, the greatest thickness of lime being on top and scarcely any underneath. This coating was not confined to twigs, but included anything that had fallen into the water, all being covered so that they lost their identity and blended closely with the brownish white bottom.

The last portion of the lake investigated was the basin. This basin is nearly circular in form, is shallow and overgrown with round rushes at the margin and increases gradually to about 10 feet depth at center. Its waters, clear as crystal, lie over a very deep bed of marl. It has three arms, one leading from the north arm of the Horseshoe Lake, one from the south arm and lastly the outlet or creek. All are so overgrown with rushes and choked with marl that boats are forced through with difficulty. The soundings made and marked in the list make the average uniform depth of marl about 30 feet. The clearness of the water can perhaps be accounted for by the fact that every particle of foreign matter, organic or otherwise which might find its way into the pool, seems to be surrounded and buried by the lime as described in the case of twigs. Whether the lime or marl be precipitated carrying down the organic matter with the marl or whether the particles attract the lime by the assimilating action of minute animal or plant organisms one result is here obtained. The water is left so pure and clear and free from foreign matter that fish or water plants can be seen entirely across the basin. Here it is well to remark that the bottom was overgrown with a plant much in appearance like a small pine tree. In the middle of the lake sound at 40 feet, a deep water plant was brought up, smelling exactly like a pole cat.*

The best samples of Balker Lake were not analyzed. The very deep samples were tough and steel-blue, were evidently high in clay and organic matter, but on the whole not so sandy as those of Long Lake.

As will be seen by descriptions on page 46, samples of water were taken from two springs, from the deepest part at sounding 41, from the surface and outlet of the basin and it can be easily seen that on account of the intensely marly nature of the lake its waters should reveal something of the marl's origin.

It is impossible to reconstruct the lake as it once existed. Its bold shores and large marsh hint at a far greater depth and volume

*See pp. 56, 89.

of water with currents which may have done something toward disturbing the evenness of so thick a layering of marl.

As in reality a small portion of the whole bed was examined the rest lying under the adjoining marsh, the cross section (Fig. 6) is rather incomplete and the individual soundings do not show the pronounced relations between true and false bottom. Attention is especially called to the sounding mid lake, which shows the remarkable difference in quality of the marl in the deep water, as it contains much iron and organic matter and only about half calcium carbonate. It has been suggested as an explanation that the organic matter of the lake upon account of the dish-like shape of the lake tends to slide into the central or deeper portions, giving them a more highly organic character.

It was especially noticeable that Long Lake contained a more caustic marl than Horseshoe Lake. In Long Lake the hands of the operators were severely chapped and seamed, while this was scarcely noticeable in Horseshoe Lake. The marl did not seem to bite.

A review of the springs of Horseshoe Lake hardly seemed to justify the theory of immediate precipitation of lime. There was no trace of marl in or around them although at a distance of a few hundred feet the deepest marl was found. Upon the whole this lake is very deeply indented in the surface of the country, having high, steep bluffs. The portion covered by water has a steep terrace or shelf, less shallows than Long Lake, with a deeper and larger lake center. It has a thicker, more homogeneous marl with considerable organic matter distributed most largely toward a somewhat clay bottom.

The next lake visited was Guernsey. This lake lies northwest of Cloverdale about $1\frac{1}{2}$ miles in Secs. 17, 18, 19, Hope Township. Its two long lobes form like Long Lake what might have once been an old river valley. This is continued by a rather narrow marsh and creek forming an outlet. This marsh, several miles away, is said to contain bog iron.

The lower lobe only could be examined, as it was impossible to get the raft through the narrows between the lobes. The lobe examined appeared something like a mitten. The wrist forms the extension, shallows and narrows leading to the north arm the hand. The main body of deep water is fringed with shallows. The thumb to the west was a long lagoon lying in marsh. The south end was

all sandy bottom destitute of marl. Yet the usual terrace was there and so close to shore that teams must be careful not to drive in far for fear of suddenly slipping off the shelf into deep water. A spring was found near the south end, of which the water was sampled in jar 9. (See page 46, Chap. IV.) A small deposit of iron was on the vegetation, but no trace of lime could be seen in the vicinity of the spring. As proddings were made from time to time up the east side of the lake a sandy marl was found which increased to a depth of several feet as usual at the approach to the narrows. There were broad flats or shallows which, being covered with marl, gave the neighboring fishermen the idea that there must be an extensive deposit of marl. Upon actual sounding it was found that the flats were covered by 1 to 3 feet of water, beneath which was 3 to 4 feet of marl and below this a tough, almost impenetrable blue clay bottom. The lagoon opening on the west side, described as the thumb, contained nothing but fine silt to a depth of 25 to 30 feet. It seems queer, but is a fact, that upon the west side of the narrow tongue of marsh dividing off the lagoon there should be pure silt of the ordinary marsh or river formation, while upon the east side in lake proper there were 20 to 25 feet of the best marl in the lake, the bottom also in the latter case showing strict terrace formation, which was tested in the usual way by Soundings 49 and 51. In this case the bottom was found nearly level and about the same depth beneath water level as that in the lagoon. West of it the difference in the terrace was, in this, the first instance cited, caused by difference in thickness of marl layer. But this is a very slight terrace. Compared with real ones previously examined there is but a four foot fall. This could have easily been displaced or washed over the sand, which is further south and to which it sinks. An examination of analyses 12A and B, 13A and B, and 14A and B shows a very interesting condition of the bed. The surface samples, 12B, 13B and 14B show by far the higher lime and in every case a much smaller percentage $MgCO_3$, but far the higher percentage organic matter and lower percentage insolubles. In other words the marl is at the surface fair marl but with considerable organic matter, but at the bottom it merges into a blue clay which of course is higher in insolubles, higher in $MgCO_3$ and much lower in organic matter, except in case of 14A. The $MgCO_3$ is not very high, and as the clay is very fine

grained, if not too deeply buried, it could be used mixed with the marl for factory purposes.

14B is one of the best samples found in the lakes and was taken in Sounding 32.

To recapitulate the important features of this lake. It is long and river-like, undoubtedly one of the old glacial valleys like Long Lake. The layering of marl lies toward the west side of the south lobe, is underlain by blue clay, is from 2 or 3 to 28 feet deep, is not as uniformly thick as Horseshoe Lake, does not cover the whole lake, is flanked upon the west side by a deep lagoon filled with silt. Its springs show no unusual trace of marl. It does not indent the surrounding hills very deeply, being the shallowest placed lake so far visited.

The next lake examined was Pine Lake. This lake, north of Cloverdale, is in Sections 8 and 9 of Hope Township. The portion covered by water when the lake was examined rendered its outline very different from that given on the county atlas. It consists of three large lobes, the narrows of which were larger and less obstructed than any so far visited. Time permitted only the examination of the south lobe and its connecting narrows. The first sounding was made at the cove or landing where stock and teams are driven and row-boats usually land. The surface of the marl is muddy, which is an unusual occurrence not found elsewhere in the lake. It may be due to the constant roiling at the water's edge. The next sounding was made across that end of the lake at a large boiling spring. This spring was about a yard across and its location was marked by a large number of bubbling fountains which boiled up through the marl 10 feet thick. This is the first case where marl was found in or about a spring. The analysis of this marl (No. 17) shows it to be remarkably free from sand or clay, but quite high in organic matter. Although the bottom from which the spring came was fine sand like the rest of the lake, and although the water was washed up through it and the marl, the ascending stream seems to have no power left to mix the sand with the overlying marl.

As the remainder of the south lobe presented no unusual appearance, a series of soundings were made across the first narrows, which were perhaps 100 feet wide. These soundings are numbered from 3 to 8 on the record sheet. Figure 7 shows the cross section of the bottom as platted from the soundings.

By this it is seen that from Sounding 3 to Sounding 7 there was a deep original channel nearly filled with marl except where gouged out in the center of the modern narrows. On the west side Sounding 8 shows another channel almost entirely filled with marl. As the true bottom shows no sudden terrace or shelf so the marl or false bottom, though it slopes to form the deep depression of mid-channel, does so gradually without the sudden step or terrace formations. To appreciate this compare true and false bottom here and in Diagram 3, Plate I. From the way the marl lies it would appear worn away in mid-channel. It would be unfair to establish this as a fact as the marl might have formed more easily about the side or points forming the narrows and so have built out into the channel.

The samples taken from this lake are analyses Nos. 16, 17 and 18 A and B, 20A and B. They average better than those of other lakes of the group. The first, No. 16 (Sounding No. 1), is the poorest. Though taken about 30 feet from shore and at a depth of 20 feet, the sample contains considerable sand which has evidently

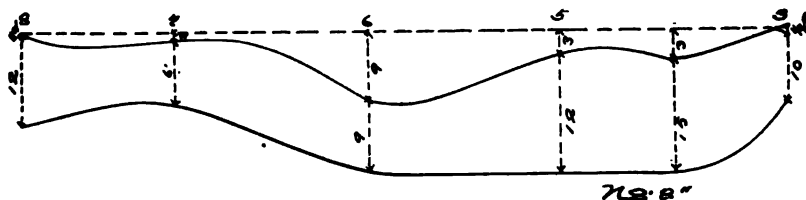


FIG. 7. Section at Pine Lake, soundings 3 to 8.

worked out from the shore. This is shown by a high per cent of "insoluble in HCl." The surface was before described as being covered with organic matter, the only black bottoms on the lake and probably due to the landing.

No. 7, taken in front of the boiling spring at 10 feet depth, shows a very high per cent of organic matter though otherwise light in Al_2O_3 , Fe_2O_3 , insolubles, and MgCO_3 . The especially low percentage of insolubles and Al_2O_3 , Fe_2O_3 are interesting, as the sounding showed the spring boiled up through a 10-foot bed of marl. At the bottom was fine sand. This sand was not mixed with marl as would appear natural, but the sample taken was unusually free from insolubles as the first column indicates. Again, this sample is the freest from Fe_2O_3 , Al_2O_3 of any taken. The spring then left none of its iron in passing through clear marl, but carried it away in solution. Near by there is an outlet to this lake and this out-

let, several miles away, contains a large deposit of bog iron ore though within the immediate vicinity there is no trace of it and the samples are free from all but slight amounts of iron and alumina; .8% to 3½%. In 19, 20 and 21 both surface (B) and deep (A) samples were taken. These samples belong to Soundings 5, 6 and 9, respectively. (See Diagram No. 8.) These soundings form part of the cross section of the narrows and are about 20 feet apart. Some investigators have thought that deep samples show higher percentage of magnesia than do shallow, so it was thought advisable to compare analyses of surface and deep samples in order, if possible, to arrive at a conclusion as to the increase in percentage of magnesia. Such a conclusion might assist in tracing the origin of marl. In the three pairs of analyses, 18, 19, 20, the first two show the highest magnesia at the surface while 20 is a little in favor of the deep samples. In two cases out of three, 18 and 20 against 19, the organic content is the greater with the increased depth. In all three instances Fe_2O_3 , Al_2O_3 is highest in deep samples. In 19, where the organic matter varies least with depth, Fe_2O_3 , Al_2O_3 varies least. This sample, Sounding 6, is, however, but 9 feet in depth, giving the least distance of any of the three soundings sampled, between surface and deep sample. It is noticeable that there is less variation in any of these components than in the soundings where distance between samples is greater. In two out of three the insoluble matter is highest in the lower sounding. In comparison of future samples from different depths it will be well to keep in mind the mutual relation with varying depth of the samples in order to find if possible the constant variation in composition of a marl bed. This would be of little aid to the factory chemist as the dredge makes a clean cut from bottom to top, but may assist in our scientific research for the origin of marl.

For the sake of clearness and to give some system to the perusal of further descriptions it is thought best to review the work upon the five lakes so far discussed.

CLOVERDALE REGION—SUMMARY.

Long Lake is covered with a sheet of marl varying from 20 to 30 feet in depth. The bottom of the lake is not level and even, but has a more or less regular terrace on the south side, a deep channel which runs from mid lake under the marsh at the present outlet,

narrowing at the same time to a width of thirty or forty feet. This channel, which forms the deeper portions of the lake, is choked at Ackers Point, about mid-way and the lakes outlet, with a depth of marl of about thirty feet. At a depth of twenty-five feet of water in mid lake there is twenty feet of marl, showing that the bed thins in water of that depth.

Besides the main channel there are many sudden holes in the outline of the original sand bottom, and also a sandy islet where pebbles and stones crop out at the surface. To each side of this islet the channel, while it is not as deep as toward the outlet of mid lake, is filled evenly with marl. The depth from surface of water to original bottom is, on the north side of the island, 27 feet, on the south side 13 feet, while the depth of water is four feet in both cases.

The accompanying map of the lake and cross sections of the bed are made to show the manner in which the marl is deposited upon the terraces. The effect of the marl in all cases is to round over and fill up holes. It deposits sparingly upon the rocky islet and fills the channels to each side. It thins toward the center, but produces a less sudden descent from the terraces than would have been found on the original bottom, before the deposit of marl.

The deposit lies evenly at both ends, and along the southeast shore, but is thin and persistent only at points which project from the northwest shore.

The lake being three miles long and but a few hundred feet wide, and having high gravel and clay hills, is very subject to washings of surface soil. Its composition is heavily influenced by sand and clay rendering it of little use for factory purposes.

The waters flowing into the lake by its springs are very hard, as were also the deep drive wells of the immediate vicinity. The lake adjoining, called Mud or Round Lake was remarkable for its contrast. It apparently received the soft waters of surface seepage, was clearly of higher level, with sand, clay and mud bottom. A trace of marl under several feet of muck was found in thirty-five feet of water. The saying that "hard water makes hard marl" was very well exemplified in these two lakes. From a view of the two so close together, yet so different in their content of marl and the hardness of their waters, it would appear that Mud Lake indented the surface of the country less and did not receive the drainage of

the springs from the deeper strata of soil. Its surface is about fifteen feet higher than that of Long Lake and the ditch connecting the two lakes had furnished water fall sufficient to run a mill.

Horseshoe Lake (Plate II) contains the deepest and most actively depositing bed of marl and the deepest of any of the lakes investigated in this region. The lake as it now exists encircles a portion of the whole basin in the form of a horseshoe, the remainder being covered by marsh. The largest and most intensely carbonated springs and lake water were found here.* This lake, running from 20 to 37 feet of marl on shallows. It also shows the same tendency to fill the sudden step made by the greatly increasing depth from the shallow terraces to deep water. In this deposit the greater variation in composition resulting from increase in organic matter, is seen every time a deep and a shallow sounding are taken in the same spot for comparison. The great coldness of the deep water of mid lake is sharply contrasted with the luke-warm water of the shallows. The great abundance of plant life in shallow water and the thick incrustation of every object covered by shallow water are very striking, as are the absence of incrustation plants from deep water.† This is the remainder of a very large deeply indented lake basin, which has held the hard waters of its deep springs for many centuries. Nearly all the basin is sealed by marsh growth. The portion remaining consists of the waters of Horseshoe Lake, which are actively depositing the best grade of marl at the surface of its shallows.

The portion of Guernsey Lake examined is remarkable for its strictly local deposit of marl. The thumb described contains very good marl on its east side and a corresponding depth of loose lake silt on its west side in the lagoon. On the one side the particles of silt are surrounded by the deposit of marl, making a marl bed with 22% calcium carbonate at bottom and 64% calcium carbonate at surface, while on the other side of the tongue of land fifty feet away there is a deposit of twenty to thirty feet of pure silt. At the head of the lake there is no marl at all, though there is a terrace and a spring of water containing 130 parts in the million of calcium carbonate, which is a fair average. It appears from this that conditions are not always favorable for the growth of marl, given the same kind of bottom and the same water. True, the con-

*See Nos. 4, 8 and 5, page 46, Chapter IV.

†Wesenberg-Lund.

ditions are not exactly identical with those of the deep deposit at Horseshoe Lake. The springs are not so plentiful or of such hard water. The sandy spot alluded to is bare and unsheltered.

Pine Lake shows fairly hard water, a good deposit of marl over the entire lake and not as great difference in content of organic matter as Horseshoe Lake or Guernsey Lake. This was a case where a spring bubbled up through ten feet of marl without bringing sand into its composition or otherwise affecting its quality. We must conclude that the immediate locality of springs has no effect upon the position of the marl either in regard to depth or quality.

The samples of water taken are interesting only from one point of comparison. For the whole list of samples and analyses of some, see page 46, Chap. IV.

CaCO₃ COMPARED IN PARTS PER MILLION.

Springs.	Wells.	Surface.	Water medium deep.	
Horseshoe 200, 160.....	70	100	117
Long Lake 100.....	160, 156	40	.....	.....
Guernsey 130.....	40	.....	.....
Pine Lake 170, 136.....	80
Mud Lake 80.....	30	.....	53.6

From these comparisons and those made with soap solution in the field, it appears: that the most intensely marl lakes have the most heavily carbonated waters, the soft water lake showing much poorer in all cases; that in the lake itself, the deep water contains the most gas and carbonates and that they uniformly disappear in every lake at the surface, the gas being lost entirely and the carbonates in a fairly even proportion. These well, spring and lake waters substantiate the idea that the water's hardness is responsible for the presence of the marl in a somewhat direct ratio to the strength of the carbonates it contains.

§ 3. Pierson Lakes.

I visited Big and Little Whitefish Lake, southwest of Pierson three or four miles, Pierson Township, Mecosta County.

The general outline of the land is a rather monotonous level, but in the neighborhood of the lakes it is considerably broken, but not as much as at Cloverdale. Big Whitefish Lake is about three miles long by a mile wide. Its shore level sinks into extensive shallows consisting of somewhere between 20 and 30 feet of marl.

At near the center a "blind island" rises from the very deep water and is covered by about 25 feet of marl. Blind islands are met with often in these lakes. They are small shallows in the deep water of mid lake. There are large flowing springs along the shores of the lake. These springs deposit iron upon the stones and vegetation at their borders, but the marl in the lake below them appears to be unaffected by iron coloring. One spring at the south end gave marked smell and taste of sulphur and was valued highly for its medicinal properties.

At its southeast corner the lake is bounded by a sandy ridge containing gravel with fossils and granite boulders. Beyond this ridge, perhaps 200 yards to the east, is a deep hole or smaller lake, about 200 feet across. This is fed by intensely iron springs and empties by a deeply cut creek into the larger lake. The sudden fall gives about ten feet of water fall for turning light machinery. The creek is very interesting. Its bottom is composed of marl which continues up its steep bank 20 or 30 feet. About half way to the top of the ridge upon the sides the marl is shown on the up-rooted stumps of large forest trees.

Between the two bodies of water mentioned is a kettle not as deep, but with sides so steep that there was some speculation as to whether the Indians had not dug it out to make their mound which was on the ridge to the east. Upon examination a crude marl was found in the bottom of this kettle under a few feet of loam, showing that it, with the low ground adjoining, had been under water. It looked as though the three, the larger lake, the hole and the kettle between had once been one and that the creek bed was once but a connecting channel.

A bed of clay was examined on the farm of Mr. Shanklin some little distance from the lake. The clay bed was covered by 2 or 3 feet of red and yellow ochre, which had at one time been dug for paint. An augur was used and the ochre and clay bed beneath penetrated to the depth of 10 or 12 feet. The samples brought up showed a fine clay which reacted feebly with acid, but was in most cases mixed with sand, which seemed to run through the bed somewhat in layers, there being found several samples entirely free from grit.

Little Whitefish Lake, two or three miles from Whitefish Lake, was visited briefly and a few soundings made at the south end. Here there was a swamp at the southeast corner which was

probed to a depth of 15 feet without striking anything but silt. The marl upon this side seemed slightly red or brownish in cast, but at the west side it was much whiter. The marl was (28 ft.) deeper upon the points or shallows running out from the shores and of the prevailing consistency. North of the marsh and jutting almost into the lake was a bluff showing 25 to 30 feet of clay which was nearly like rock, of light color and was calcareous.

§ 4. Lime Lake and vicinity.

The lakes about to be described are near Cedar Springs in the northern part of Kent County. The country through which our guide led us showed very distinctly the effects of the glacial action. Steep hills, waterways, creeks and small lakes produced a very undulating surface. The first fact worthy of notice was very strikingly illustrated in the examination of road cuts in several side hills. These hills were generally coarse sand which was thoroughly seeded with small pebbles and boulders. At varying distances up their sides, clay strata projected slightly, or their exposed surfaces were worn down and hidden by sand and gravel from above. These clay banks are typical of half the clay in Michigan. In color it is light or ashy gray. Its texture or grain is ruined by the admixture of fine sand. Upon addition of acid it effervesces more freely than many samples of marl because it contains so high a percentage of carbonates of calcium and magnesium. Upon a further examination of the bank or hill the carbonated condition of the soil is found to continue not only in the clay, but also in the loose and apparently pure sand as, upon contact with acid, the surfaces of the sand grains freely effervesce.

Parallel with the stratum of clay are often found small ledges or boulders of a matrix of coarse sand in which are cemented small pebbles. The upper surface is even as if smoothed by the leveling action of water, although the rock, as it has now become, is fifty feet above the level of a stream and buried in a hill. The lower surface of this rock or tufa is uneven and jagged. Upon the addition of acid to this rock it also, as in the case of the sand and clay, bubbles with escape of gas, and the particles of sand and the pebbles fall apart showing that the matrix or binding element is not the insoluble sand, but the very soluble carbonates.*

A comparative test for hardness was made upon the springs and creeks of this region during the trip and all were found to be very

*A similar recent sandstone occurs beneath the clay bed at Harrietta. L.

hard. Lime as a carbonate was found to permeate very thoroughly the soils of the whole district, and the soil mixing effect of glacial action was very marked.

Lime Lake.

The first lake visited in this region was Lime Lake. An old kiln was still to be seen marking the place where marl from the lake had once been burned for lime. The lake as a whole made a very sharp and deep indentation or circular hole in the plain of the surrounding country. The shallows on its shores formed a white but narrow margin ending in an abrupt terrace and very deep water toward the center of the lake. The shallows, the dry land of the valley, and the broad entering valley of a small creek, formed a solid body of very white marl from fifteen to twenty-seven feet in thickness. Shells, large and small, constituted nearly the entire body of marl even at the greatest depth and they preserved their form perfectly. This is certainly one instance, at least, in which shells can furnish nearly if not all the excuse for the origin of marl.

Several samples of marl taken a few feet below the surface, upon drying, turned from nearly white to a pronounced red. This was very likely due to the oxidation, upon exposure to air, of the ferrous or nearly colorless iron to the ferric state in which the color is red. The valley opening into the lake from above was very large and probably once formed an old glacial valley. It connects Lime Lake with several higher ones and is a pure marl bed with but slight covering of surface soil.

Twin Lakes.

These lakes were remarkable for their great contrasts with each other. They had no visible union, but they were said to connect with each other by an underground channel. The lower one was shallow and sandy, the upper one was a hole between huge banks which, in cuts made by washouts, were almost identical in nature with the sand hills before described. Its banks or bluffs, fifty feet high, descended with but a step for a shore line, directly into water, making no shallows whatever. So abrupt was the descent to the bottom that one standing on shore could shove a pole out of sight in the water without touching bottom. The lake is said to be one hundred and seventy feet deep, according to the measurements of the Fish Commission. The springs emptying into the lake formed a glistening scum of iron. This lake is a very good example of the hundreds of holes made by glacial action and without which we could not have the conditions necessary for the formation of marl.

§ 5. Fremont District.

Fremont Lake and the town of Fremont are situated on the Pere Marquette railroad in the northern part of Sheridan Township, Newaygo County. The country surrounding the lake is rather level and the lake makes but a slight indentation in the surface. In sharp contrast to this the lakes in the hilly country before examined seemed to depend for the depth and extensiveness of

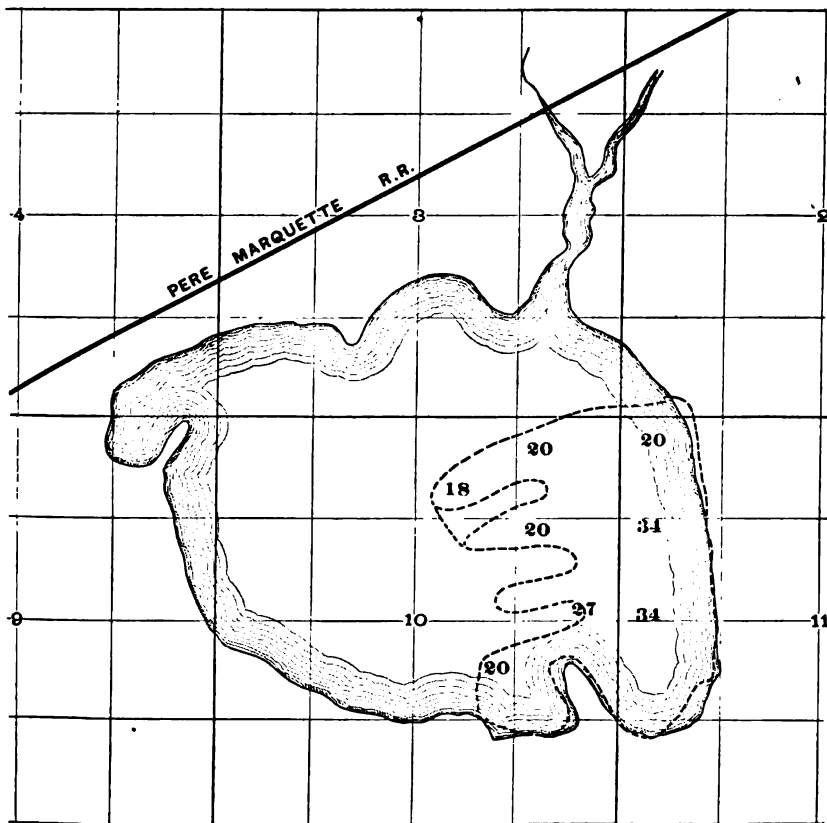


Fig. 8. Fremont Lake, Newaygo County.

their deposits upon the comparative depth at which their basins were sunk below the level of the surrounding country. Fremont Lake has a very shallow basin and it therefore differs entirely from the regions before mentioned.

The lake is to be the site of a fourteen-rotary cement plant to be run by power transmitted from the other factory to be built at Newaygo.

The map of Fig. 8 represents Fremont Lake or the portion of its basin covered by water. The dotted line encloses that portion most available for cement purposes. The depths of marl soundings are shown by the figures. The drawings together with the accompanying analyses were kindly loaned us by Mr. John Cole.

The lake examined closely on the side toward the town shows marl shores covered partly with sand. The shallows which are very extensive extend out toward the center of the lake as long, parallel peninsular shallows. The change from shallows to deep water is very abrupt, even between the peninsulas. These abrupt changes are very similar to those at Cloverdale. The soundings in this lake show the shallow marl toward deep water. Soundings of eighteen and twenty feet are found toward the center as contrasted with thirty-four feet at the inside edge. There is a blind island in the center of the lake which brings within reach much valuable marl.

The peninsulas above mentioned are covered with from one to three feet of water, the marl has no covering of organic matter and supports a thick growth of the cylindrical rush known as marsh-rice which is so prevalent as to be almost characteristic of marl beds.

The analysis of the sample of marl by Prof. Delos Fall of Albion was as follows:

Silica	2.28%
Aluminum and iron oxide	1.60
Lime	88.25
Carbonate of magnesium	1.40
Organic matter and undetermined	6.47
Carbonate of lime after the removal of organic matter	94.85

Beneath this marl lies a blue clay which was analyzed to determine whether it would be of proper composition to mix with clay in the manufacture of cement. It was found that the clay directly underlying the marl contained over seven per cent magnesium oxide, which was considered unsafe. The startling fact from a scientific point of view is the sudden variation in content of magnesia in the marl and in the clay immediately beneath it. 1.40% magnesium carbonate equals .7% magnesium oxide and the proportion of the oxide in the marl to the oxide in the clay beneath is then, as .7 to 7. For this reason either a totally different agent or

the same agent, with greatly varying power, must have controlled the deposit of magnesia in the marl and that beneath it in the clay of Fremont Lake.

Mr. Cole showed me another clay from a different part of the country, which was to take the place of that just mentioned. It appears as a dense blue shale and the following is the analysis as given to me by Mr. Cole (chemist not known):

Silica	42.94%
Alumina (Al_2O_3)	12.94
Oxide of iron	5.73
Calcium oxide (CaO)	12.93
Magnesia	2.97
Loss by ignition	18.94
Alkalies (sulphuric acid, etc.)	4.07

There were said to be numerous hard water springs in the vicinity. A drive well near the station was examined and showed very hard water. A well bored near the lake failed to strike anything but marl till at a depth of thirty feet it penetrated a limy clay. The clays of this region are very calcareous.

§ 6. Muskegon District.

Bear Lake just north of the mouth of the Muskegon River, was visited and probed for marl. It appeared after investigation that Bear Lake was but the old mouth of a river. Muck and silt to the depth of 35 feet was found, but no marl, excepting at one place. Near its outlet was a streak of clay at right angles to the outlet and to the mouth of the Muskegon River. This clay was found to run under the lake and above it and beneath the silt was a foot or two of genuine marl. Several soundings were made at the mouth of a creek emptying into the lake and also in the rushes at the head of the lake. The bottom was in every case a foundation of fine sand covered by many feet of silt.

The Muskegon River flats were said to contain marl and several samples were submitted to me by Prof. McClouth of the Muskegon High School, but nearly all of them showed an intimate mixture of clay, sand or muck with the marl demonstrating nicely what has usually appeared, that marl generally loses its individuality and becomes an admixture of marl with sand, clay or muck in the neighborhood of running water.

§ 7. Benzie County.

Benzie County contains a number of marl lakes, several of which are drained by the Platte River.

Also a company was formed to work the marl in Herring Lakes, five miles south of Frankfort. These two lakes are connected by a stream which has a waterfall of 15 feet. This is to be obviated by cutting a canal through a bend in the creek partly draining the upper lake. This lake contains a deposit of marl about 30 feet in depth. It is fed by numerous springs, which form a network of creeks. To the east the lower lake is very deep and is connected with Lake Michigan by a short channel which is to be deepened for the entrance of large lake boats.

The bluffs of clay about Frankfort were examined for a cement clay, but none was found. Some clay was quite free from grit, but all was highly calcareous. On a farm north of Frankfort there was a sink hole, some 300 feet from the lake. There was no visible drainage, but upon the bluff opposite the hole there was a seepage of water from between the clay and the sand lying above, showing that the water might in part be held in and turned lakeward by a dense underlying stratum of clay. This may also explain the drainage of some marl lakes which have perfectly fresh water but no visible outlet. Crystal Lake was examined but showed no signs of marl. It had a very gradually increasing depth and pebbly beach like Lake Michigan and was unlike most marl lakes in formation and slope. The Lake Michigan bluffs, which are here very high opposite the lake, suddenly sink to within 15 or 20 feet of its level. The sharp well-defined channel with abrupt banks on each side seemed to show a former connection between the two lakes. A comparative test of hardness of water showed them about alike.

In Frankfort River, south of the town, there is a large elbow or basin formed by the river bottoms which broadens into a large marsh to the south. This marsh looks as if it could easily have been a shallow basin or lagoon. It is said that several thousand acres are underlain with 2 to 3 feet of marl. That examined was under 2 to 3 feet of muck and was very white.

§ 8. Harrietta.

In the trip from Frankfort to Cadillac the clay banks of Harrietta were passed.* It was near this point, the highest in that part of the State, that marl was reported as lying in a creek and upon its banks. Marl is deposited everywhere regardless of elevation.

§ 9. Escanaba.

The country about Menominee is largely limestone. A lake in Sec. 6, T. 24 N., R. 26 W., is said to be marly. No marl lakes were popularly known around Escanaba.

*See Part I, p. 53.

At Escanaba a light prospecting outfit was made consisting of the following:

40 feet of $\frac{3}{8}$ -in. pipe, cut in 4-foot lengths.

Couplings for the above.

$1\frac{1}{2}$ -in. common wood augur bit welded to short piece of $\frac{3}{8}$ -in. pipe.

1 alligator wrench.

This could be loaded into a sack, strapped up and checked from one station to another.

It is found that for soundings in deep water for marl $\frac{1}{2}$ -inch pipe is the safest, although the smaller $\frac{3}{8}$ -inch pipe is lighter and can be raised or lowered in the marl easier, but is liable to bend out of shape and tear out at the couplings.

A 2-inch bit is a good medium size. A larger one requires too much work to raise it through the marl. A smaller one does not hold the marl in its coil. For practical purposes this is the most serviceable outfit for the average marls of Michigan. But in the Upper Peninsula marl was found too hard to penetrate by this means and in the Lower Peninsula marl and mud are sometimes too soft to be held in the worm of the augur. For all round sampling we find the outfit at Cloverdale very good though bulky. At Little Lake, the junction of the Chicago and Northwestern and the Munising R. R., Marquette County, Upper Peninsula, several lakes were examined. Their water showed in comparison as 2.7 to 11-13 as contrasted with that of Lake Michigan. This was quite soft and bore out the result of investigations at Cloverdale. The lakes were in a low, level country themselves, had very low banks, and nothing but seepage springs. Upon sounding they gave depths of marsh silt varying from 12 to 25 feet upon a fine sand and gravel bottom.

§ 10. Munising.

At Munising no marl lake was found in the immediate vicinity. I was informed by the superintendent of the road of a marl lake once discovered in sinking a shaft. The boring was carried through 20 or 30 feet of muck, when the drills passed through about 30 feet of marl and then into sand and rock again. The well filled and the liquid marl was pumped up as it constantly filled the hole and prevented progress. Finally the upper layer of denser muck sank like a flap till it shut out the liquid marl and the boring was completed, no ore being found.

§ 11. Wetmore.

At this village there was a large creek fed by a mass of boiling

springs in its bottom. This bottom consisted of a very dense white marl covered by a few inches of silt. When the augur penetrated with the greatest difficulty and was pulled out with a specimen, a new spring boiled up in the puncture of the crust made. This point is near the divide of the Upper Peninsula upon the side which drains into Lake Superior. The creek is bounded on either side by somewhat low hills. The marl obtained was half way in consistency between marl and limestone. It was rather granular, though the particles themselves examined under microscope cannot be distinguished from those of dried marl. The marl is an almost pure white and very heavy considering its volume in comparison with ordinary marl. The creek is said to drain several lakes nearly upon the divide.

§ 12. Manistique.

Here lime kilns were visited. The whole country is limestone and there are no lakes or flowing springs or wells in the immediate vicinity. The limestone itself is over 30% MgCO_3 , but burns well, making a good lime. A sample of marl from a dried up lake-bed some 30 miles distant was shown me. Its analyses revealed 95% CaCO_3 , and it seemed one of the purest samples seen in my trip, being, with the exception of a little darkening organic matter, pure white. The analyses showed but traces (slight) of MgO and this too in a country noticeably abounding in magnesian limestone. The lake-bed from which this came showed a basin-shaped depression of about 37 acres filled with purest marl from a shore depth of 1 to 2 feet constantly increasing to a center depth of 29 feet. This is a good example of a completed lake.

§ 13. Corinne.

A spring creek was examined and a small bottle of water taken.* Most of the bottom of the creek was underlain as at Wetmore with a very hard granular marl 2 to 3 feet deep with clay beneath and one or two feet of muck on top. There were no indications that this had been a lake bed in very recent times, though the ground which formed a small swamp had very likely been under water for differing lengths of time. A lake about three miles farther south was visited and had a peculiar history. It was said that it increased in size during the spring months, but in summer, July and August, it suddenly disappeared and it was wondered if it found some crevice in the marl and suddenly emptied itself. It is prob-

*Sample of water taken from large spring. See (No. 2).

able that the lake filled up from spring rains and then gradually dried and by summer it had got so shallow that when steady hot weather came the thin sheet of water left evaporated quickly and the shore line advanced very suddenly. When the lake was visited in late July it had 3 or 4 feet of water upon it and was one great shallow of marl one mile or more long and a quarter mile wide. The marl was the purest seen, but was so dense and granular that the augur did not penetrate over five feet. The marl, however, formed rather dense layers. As the augur penetrated it it would sink easily for a foot or two and then strike an almost impenetrable layer which seemed like sand, but the specimen obtained would be very hard marl. It is probable that this stratified condition or layering of different density is caused by the sudden drying and baking given the crust during the annual drying of the lake. The lake was in an extensive forest bottom and I was informed that it was fed only from the surface waters which collected in the wetter portions of the year.

I could hear of no marl in the region of Trout Lake, but near St. Ignace there were deposits of marl and dolomite. No marl could be located in the neighborhood of Mackinaw City. Little Traverse Bay had marl underneath the sand as shown by driving of spiles for piers.

At the straits and for many miles inland the immense area covered by limestone scraped bare of glacial drift perhaps shows where the lime of our marl once originated no matter how subsequently deposited in the lakes. The immense number of small, smoothly rounded limestone pebbles show that a great body of lime must have at one time been washed away by the action of water, being removed in the form of either a fine sediment or a solution.

§ 14. Grand Traverse region.

The district about Traverse City was next visited. The marl upon a low basin on the asylum grounds was examined and found to contain an underlining of marl about 2 or 3 feet deep. Here it became evident as at Frankfort that an originally greater depth of water lying over the marl did not imply a greater depth of marl, but rather the opposite. This is considering the water level of Michigan as a whole. This, together with the thin bed at Frankfort and others very near the water level of Lake Michigan, showed unusual thinness. In this case a large basin had been grown over with muck and covered with debris to the depth of 4 to 5 feet and

only showed where a large ditch had been dug. The marl was very hard and dense, very white.

The lakes about Interlochen were next visited. Duck Lake had been dammed to allow the floating of logs so that the marl being under greater depth of water was more difficult to examine. The effects of sand washing over the marl were very noticeable in this lake, probably on account of the increase of water depth. No marl was found in the immediate vicinity of the opening of any spring or creek into the lakes. In the bay or lagoon on the east side, made by the peninsula, water and marl were shallow enough to permit of sounding with the result of a gradual increase in depth of marl from shore to center. (Fig. 9.) Hard sand prevented a like test upon the opposite shore. The marl was in no case exposed close to shore excepting on the shore of the peninsula, which was very low and overgrown with trees and may have been but recently lake bottom, though upturned stumps showed no traces of marl. Upon the point itself there was a shallow coating of marl which increased but slowly at greater depths of water. The deep marl

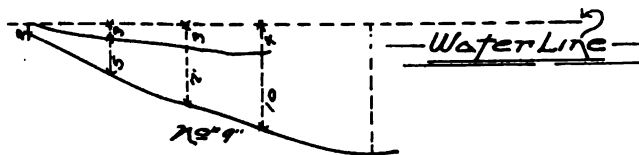


Fig. 9. Section showing soundings at Duck Lake.

extended to a greater depth than 20 feet of sounding pipes and lay to the east of the peninsula where it joined mainland. Upon the west shore of the lake there was a coating of sand with no marl in or about the outlet. There is marl in the deepest parts of the lake. Lake rice reeds in 6 feet of water were coated with marl deposit. No Characeæ were visible. This was long known by the logging men, who in raising the weights let down to pull rafts, brought to the surface the gray mud. In general this lake as viewed seems to be a very marked case of the washing of sand from shores onto marl. The marl was undisturbed, was at the center and upon the peninsula where it thinned toward shore.

The lake opposite Duck Lake, into which Duck Lake emptied, showed nothing but sand, shallow sand shores and seepage springs.

§ 15. Central Lake.

Central Lake, also called the Intermediate Lake, being one of a series or chain, extends for some distance along the coast and

North Island* is very small, has upon it but few trees, is 30 or 40 feet long, 20 feet wide, and has its longest axis from east to west.

Soundings were made first from the south, approaching from the median line of the lake to the small strip of dry land forming North Island. The following is a table of soundings on and about North Island (see Fig. 11 and Diagrams 11, 11A and 11B of Plate I) :

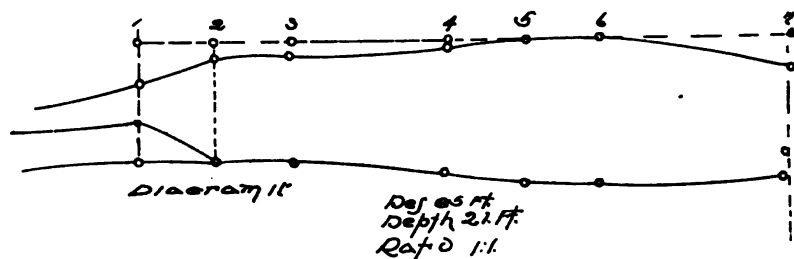


Fig. 11. Section across North Island, Central Lake. See also Plate I.

No. of sounding.	Depth of water.	Depth of marl.	Location.
1.....	5	5	50 ft. S.
2.....	2	14	40 ft. S.
3.....	2	14	30 ft. S.
4.....	6 in.	17	10 ft. S.
5.....	Dry land.....	19	On S. shore.
6.....	Water's edge..	20	North shore.
7.....	Dry land.....	21	East end.
8.....	Dry land.....	21	West end.
9.....	Water, 4 ft....	15	25 ft. N.

The regularity of increase and decrease in depth of marl, the steady variation in the relation of true bottom, marl, and water depths, is very striking and has been met with in but few other lakes.

The island was about 40 feet long by 10 feet wide at the center and was oval shaped. A shallow of weeds extended north and south about 50 feet at right angles to the greatest length of the island, making an oval-shaped island, surrounded by an oval-shaped belt of shallows, the ovals being at right angles to each other. The island itself was barely above the water's edge and was solid marl except for an inch or two of loam on top. Several trees grew on the dry ground which could be crossed easily on foot as the marl island seemed quite solid, which is not usual with marsh islands of this kind.

Upon the shores, especially the north shore, the light shells had been sifted at the water line by the action of the waves, so that the

*See Plate I, Diagram 11B.

shore was a mass of shells of all sizes from a pin-head to an inch in diameter, and also intermixed with the shells were pebbly accretions something like those forming the coarse grained marl beneath the woods to the north, before mentioned.

Here it is very easy to see how shells could be broken into fine particles and merge with a bed of marl, losing their former identity. Several large clam shells were noticed lying just under the water's surface, upon the marl. These crumbled when grasped between the fingers though they had once been very strong hard shells. It is very easy to see that if this is the condition of a large clam shell,

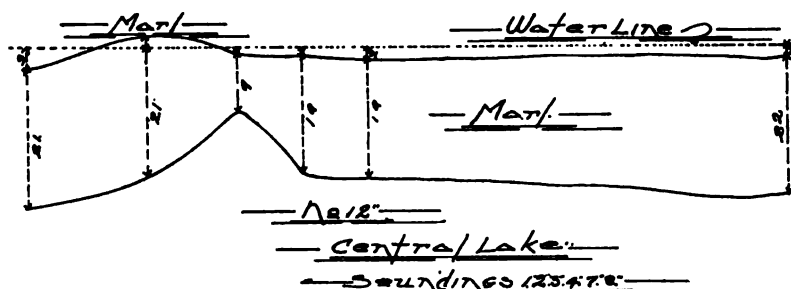


Fig. 12 Section across South Island, Central Lake.

the more delicate shells would be crushed by a much smaller pressure.

South Island,—considerably larger and lying $\frac{1}{2}$ mile south—was next examined.

It was one or two hundred feet long, oval-shaped and with its axis north to south, or at right angles to that of North Island, but in a line with the axis of the shallows of North Island. From the south end of South Island, shallows run to the south end of the lake. These shallows, the deeper channels on each side and the approaches to South Island on all sides, are all solid marl of fair quality with no surfacing of muck or silt whatever.

The soundings taken about South Island and on to the south end of the lake are as follows:

No.	Depth of water.	Depth of marl.	Location.
1.....	1	9	Close on S. E. shore S. Is.
2.....	1	19	10 ft. S. No. 1. Away from shore.
3.....	2	19	10 ft. S. E. No. 2.
4.....	2	22	70 ft. S. E. of 3.
5.....	5 ft.	20	Mid-channel S. E. of lake.
6.....	1	27	At extreme S. end of lake.
7.....	3	21	West side of island.
8.....	Light muck 2 in.	21	Center of South Is.

By consulting this table and the figure (12) accompanying it, it will be seen that the outcropping of the island of marl is produced not by an added depth of marl, but by a rise in the true sand bottom of the lake. This rise in level is sharp but uniform, the depth of marl being greater if anything away from the island. It helps to solve no problem concerning the formation of marl excepting to show that the marl behaves like any thick layer either of chemical deposit or sediment. It lies like a thick sheet over projections such as this, making them less pronounced than they would be without the covering.

Also notice that the soundings of South Island are deeper than those of North Island, not on the island, but immediately around it. The island is larger and judging from the size of the trees and thickness of the muck, has been first exposed by the slowly receding waters and has probably had somewhat more of the marl washed off of the higher parts on account of its longer exposure to wave action of the lake and leveling influence of water. The two series of soundings show a gradual increase of depth of marl from the north to the south end of the lake, where in tall pipe-stem reeds and one foot of water, the deepest sounding of marl (27 feet) in the lake was made. These two series as compared with that made in the woods and immediately west are deeper and show a whiter, more finely divided marl toward the south where in the deeper parts it loses almost entirely its granular character and brownish trace of oxides of iron.

The north end of the lake a mile and a half or more north of Central Lake was visited and a brief attempt made to examine the conditions there. They were strikingly different. While at the south end there was no sign of muck or any organic covering, here there was found everywhere 2 to 8 feet of very fine river silt. Beneath this was 6 to 10 feet of marl, the deepest having a bluish tinge.

The striking features of the lake were the granular appearance of a few beds, the gradual change in depth of marl and lack of sudden irregularities in bottom. Perhaps the whole can be traced to the slight fall of level of the lake, there never having been any current to disturb the original bottom of the marl deposited upon it. There is but 3 feet fall in eight miles in this chain of lakes.

There are many good springs of hard water flowing into the lake. The samples, 8 to 11 inclusive, represent the waters of this region (p. 46).

A mound spring examined, of which there are said to be several, is very peculiar, seeming to be formed by the water issuing from a side hill with a sloping clay bank, down which the water finds its way to pile up for itself a mound, and to boil from the top of this. The mound, four or five feet high by six broad, consisted to the depth sounded, about 10 feet, of a sandy bog iron ore mixed with clay below, making it withstand the seepage of water, and above with muck. The water itself carried up with it as a fine sediment a marly clay. (See Analysis 28, page 21.)

This mound spring may be of interest perhaps as showing what a limy water will form upon being stopped and allowing to deposit upon issuing from a spring. No pure marl was found in the vicinity. A very interesting fact was its absence.

The clays of the vicinity were next examined.

The hills west of the town were in some cases strewn with glacial boulders and were more largely of sand and gravel than those on the east. On the east side was a brickyard that showed very nicely the thorough mixture that the clays of the vicinity had undergone. The clay as dug for use was somewhat moist and capable of being picked. A lump upon drying and examination showed a very fine grain, and was full of carbonates. On slicing a section of clay the different color of the fine layers gave it a highly streaked or stratified appearance, and these layers were rumpled and bent almost like the grain of curly maple, showing that the bed must have undergone great disturbance after being laid down. An inspection of the whole cut showed an upper layer of sand, a fine much rumpled layer of fine dark clay, then beneath this a fine bluish sand, hardly distinguishable from clay at first sight.* The whole hill looked as if it had been scraped together by some great power, and just before the mixture of layers became intimate, and they lost their identity, the movement ceased. This was the one of the lowest of a series of low hills, the highest of which was at an elevation of between 100 and 200 feet above the village.

The clay hills above Mr. Crow's farm were next visited. It was found that the clay anywhere near the level of the lake showed a strong heavy admixture of carbonates, but the shales higher up in the hills were freer from them. On the farm in question clay en-

*The same contortion of the clay laminae may be noted at Clippert and Spaulding's yard in Lansing (Part I, page 56), and at the location described by Dr. C. H. Gordon, in the Annual Report for 1902. It appears to be due to a readvance of the ice sheet, after the clay had been laid down just in front of it. L.

tirely free from carbonates was found, but mixed with shaly pebbles, which were very heavy in iron and somewhat gritty. There is no doubt that in the hills about the town a genuine shale of fair quality for cement manufacture could be found.

§ 16. East Jordan and vicinity:

The marl lying at the head of the south arm of Pine Lake* and about the mouth of the East Jordan, in the large valley once forming a continuation of the lake, was next examined. The bed was reached by steamer from Charlevoix. At Charlevoix, where the railroad crossed the outlet of the lake, marl was noticed nearly worn away by washing of the water and in most cases buried by sand, but is seen in streaks where it is exposed on the bottom. Its only significance is its presence in this part of the lake in a very thin layer.

Along the shores of the south arm of the lake layers of marl of a few feet in thickness were seen cropping out under the banks washed away sharply by the action of the waves.

The general appearance of the valley examined was very similar to that of Central Lake. Sharp hog-back ridges from high hills ran down somewhat parallel to each other and at right angles to the length of the valley, which is clearly the result of glacial action. A series of soundings were made to determine the manner in which the marl was deposited. So far as found the marl lay in the form of a basin showing 2 feet at the edges to 20 feet in the center, the center of the basin corresponding somewhat to the center of the valley. Upon the whole the marl lacked the granular appearance found at Central Lake, but was not of as uniformly great thickness and was covered with from 5 to 10 and 15 feet of muck and swamp growth and in most places with heavy forest growth or its remains.

The disturbing action of a current of water was here noticed, for at the mouth of the river and at the head of the lake the marl was covered with many feet of silt and mixed more or less with sand.

As a rule the whole of this bed was underlain with blue clay. A large area of land suitable for tillage, forming a rather dry tableland with the old deeper channel of the lake surrounding it, was covered with a light muck, 1 to 3 feet of marl and then very tough reddish or blue clay. In the above instance if marl has any value as fertilizer it should, upon the admixture of muck, marl and clay, produce splendid crops, as was already shown in one or two in-

*See reference in Davis' paper.

stances where the land was utilized. It is a significant fact worthy of notice for its bearing upon the origin of marl that these clays at or below the level of marl beds are nearly always heavily impregnated with carbonates. One sounding that showed well the condition upon the table-land was as follows: One or two inches of surface soil, 2 feet marl, 3 feet tough red clay, 15 feet black clay, water and gravel bottom.

Upon the whole the marl of this section lay in a basin shaped depression nearest the water, but spread in a thin layer over nearly the whole valley. It is covered with forest or thick layers of muck in most instances and in others mixed with the debris of silt and sand brought down by the rapidly flowing river. It is, therefore, scarcely available for cement manufacture, but may some day be used to mix with and make more tillable the tough clays of the valley.

The clays of this region, however, were of greatest interest. They were of two somewhat distinct types. Those before mentioned were a fine-grained sediment laid down at or below the level of the marl. Black, blue and red were distinct colors noticed. They were all very tough and dense. In a drive taken 8 or 10 miles south and on the west side of the valley the clays of every color and condition from fresh sediment to a heavy shale in place were examined.

Those examined rather low down the bluff nearer the valley, always showed carbonates and more or less admixture of grit, probably brought down by water. As we ascended in the cuts, clay in various stages of weathering from an almost compact shale to completely disintegrated soil could be seen. The color also varied, being of a yellowish or greenish tinge. These were in a number of places quite free from carbonates, but the shales were always coarser grained and would, while being more compact, dig and grind hard.

Finally an old mine shaft, where an attempt had been made to find coal, was visited. A heavy black, coarse-grained shale had been pierced by a shaft to a depth of 75 feet. The shale was nearly like rick and cropped out at the surface, breaking up and seaming where exposed to the weather. It reminded me very strongly of the Coldwater shale visited in the southern part of the State.* In the seams the shale was reddened by oxidized iron and it was said

*It is, however, the Devonian black shale. L.

that occasionally pockets of iron pyrites were found in it, although none could be seen at the time.

A brickyard was then visited on the east side of town which contained strata of different colored clay and sand, much as at Central Lake, except that the level of the layers was not disturbed. All this clay, however, showed the presence of carbonates in very large quantity.

§ 17. Manistee Junction.

Lakes about Manistee Junction were next visited. This part of the country shows very well the condition of the lakes and the outline of country prevailing in a large part of the marl districts of the north part of the State, to-wit: an almost level pine plain in which suddenly occur drops below the level of the surrounding country without the slightest warning, much like a hole upon a level plain.

A small lake was examined. This was circular in form and contained the deepest marl (20 feet) at upper end. This marl was bare of muck and covered only by water. Upon the west side a test was made of a shelf like those found in other lakes, these shelves probably corresponding to the bare shelves found about Central Lake and East Jordan, which marked the recession of the ice. Near the shore were ten feet of marl and shallow water, while out 12 feet there were 12 feet of water and muck. At the lower end the conditions were the opposite of those at the upper. Here were found 26 feet of muck, beneath which were 4 feet of marl. Fine sand was the bottom in every case where soundings were made. The quality of marl was poor, being much mixed with organic material and sand. Notice the parallel case of Central Lake where silt and fine muck deposit shifted toward the outlet, marl being thinner. The water of this lake and others visited in this vicinity was tinged deep brownish red, lacking the remarkable clearness of most intensely marly lakes.

Long Lake next visited was cut deeper into the surrounding country. The marl did not show upon the water's margin which was of compact sand, but farther out, away from the shore, was a fair quality of marl and a good extent of shallows. Soundings were not made as no way could be devised to get upon the water.

Calhoun Lake could not be reached in its deep parts where the marl, if any, was located. A marsh near here drained by a creek and practically dry showed good marl 15 feet thick, below one foot of muck. It was as usual in the form of a basin. No distinctive

marks could be found to separate it from numerous marshes in which marl has not been found.

Marl was also reported in hills between Reed City and Clare. This appeared to be a high clay country and rolling, quite distinct from the sand plains.

§ 18. Rice Lake.

This lake is situated in Newaygo County, Town 11 North, Range 12 West. The greater part of the marl examined belongs to Messrs. John H. Kleinheksel, Henry Beers, and Dr. M. Veenboer. The above map was prepared by Prof. Kleinheksel, who accompanied me during the survey of the bed.

The lake abruptly breaks the level of the pine barrens and on account of the present condition of its bottom affords especial advantages for the study of its marl. From the appearance of the large lowland or marsh the water has not for some time occupied the whole depression indicated on the map by the double traced outer line "A," and a later limit is well defined by the presence of a thick growth of scrub oak which encloses the area covered by the recent lake. This older water line is shown by the outer single line marked "B," and the more recent one by the inner line "C." Between these two shore lines, the old and the new, is found a considerable thickness or accumulation of marl ranging from two to twelve feet and lying under an overgrowth or accumulation of solid land some six or seven feet in thickness. This land is covered as before mentioned by a thick growth of scrub oak.

By a system of large ditches the lake is still further drained till it has shrunk within the inside shore line to its present limits as marked on the map* (Fig. 13).

With the above understanding, the first notable fact revealed by the numerous and carefully located soundings is that as far as could be discovered, the center of the marl basin is not exactly under the center of the water basin, nor the present lake. The center of the marl basin is very clearly shown to be in the northeast quarter of the southeast quarter of Section 10. Around this deepest portion the gradually decreasing depths group themselves. The sounding of twenty feet in the above-mentioned section forbids an increase of depth toward the water as do the soundings of twelve feet and twenty-two feet in the quarter section adjoining it on the right. The soundings made up the center of the present lake still

*The original U. S. Land-office Survey in 1838, was made in January, and no lake was recognized. The re-examination in 1854, sketched in a rather small lake. In hardly any two maps has the lake the same shape.

further deny the presence in mid lake of any marl center. The fact is then established that in the case of this lake the greatest body of marl does not lie beneath the deepest portions of the lake. Furthermore the marl as sounded extends in its location toward the large north and east lobes of the lake as marked by the line of bluffs forming the original depression.

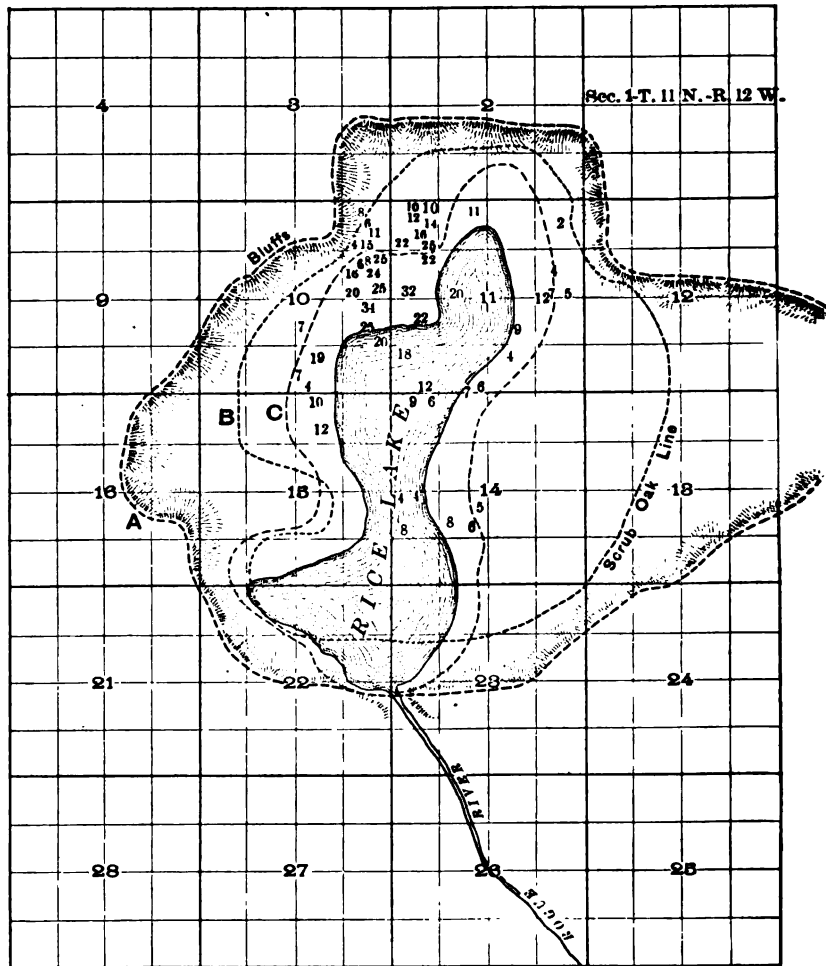


Fig. 13. Rice Lake.

The next point of interest is the rapidity with which the surface has overgrown and sealed up the present deposit. This deposit is covered by some three to five feet of tangled roots of marsh growth, forming a layer which jars for yards around with the weight of one's tread. This growth, though light and easily penetrated, is thick and must have nearly all formed in the few years

since the lake has been drained. It leads us to beware how we judge of the age of a marl bed or the length of time since it has ceased depositing by the depth of its covering or surface.

The material underlying the marl was in all cases found to be a fine lake or quartz sand, such as has been met with in the majority of lake soundings. One peculiar feature here was that just as the augur passed from the marl into the sand, it brought up a greenish layer which contained little sand, and was a grade between organic matter and marl. This is the foundation upon which the marl started its growth, and should be of the utmost importance in the study of the method by which it is laid down.

Having noted the surroundings of the marl, the final matter of consideration is the marl itself. The marl which was studied most closely in regard to quality was taken toward the center of the marl basin in deeper soundings. Though the examination carefully covered two quarter sections, the quality of the marl throughout remained surprisingly uniform. From the accompanying analyses by Prof. Frank Kedzie of the Michigan Agricultural College, and those selected by Prof. John Kleinheksel and analyzed by Prof. Delos Fall of Albion, it will be seen that the marl is rather high in insoluble matter and low in carbonates. Of this insoluble matter a small and constant part is quartz sand met with in many marl lakes and seemingly independent of the sand washed in by drainage. The organic matter though high is steadier than in most lakes, remaining the same through all the deep soundings. The analyses by Prof. Kedzie, Nos. 1 and 2, are at surface and 35 feet deep respectively. The variation in organic matter and magnesia is slight. These analyses illustrate the fact that the deeper parts of the bed vary but slightly, probably owing to the distance from hills and surface washings of all kinds.

Following are the results of analyses:

Agricultural College, Nov. 25, 1899.

	No. 1
Insoluble matter	6.66
Oxides of iron and aluminum	1.34
Calcium oxide (equivalent to 71.66% Ca CO ₃)....	40.12
Magnesium oxide	1.10
Carbonic acid gas	32.50
Organic and undetermined	18.28

(Signed) FRANK S. KEDZIE.

Agricultural College, Nov. 14, 1899.

	No. 2
Insoluble matter	4.36
Oxides of iron and aluminum	2.36
Calcium oxide (equivalent to 76.82% calcium carbonate)	43.01
Magnesium oxide .....	.97
Carbonic acid gas	34.24
Organic and undetermined	15.05
	<hr/>
	100.00%

(Signed) FRANK S. KEDZIE.

Albion, Mich., June 22, 1900.

Prof. J. Kleinheksel, Holland, Mich.:

	No. 3	No. 4
Silica, SiO ₂	2.84*	8.67†
Alumina, Al ₂ O ₃	2.76	3.55
Iron oxide, Fe ₂ O ₃	none	trace.
Carbonate of lime, CaCO ₃	79.55	65.67
Carbonate of magnesium, MgCO ₃	none	none.
Sulphuric acid, as SO ₃	3.15	2.50
Organic matter, etc.	11.70	19.58
	<hr/>	<hr/>
	100.00	99.97

DELOS FALL.

§ 19. St. Joseph River and tributaries.

In and about the mouth of the St. Joseph River there are beds of marl. Very small creeks have in the meadows surrounding them, small beds 1 to 3 feet thick of marl. Hickory Creek and Paw Paw River, which has a large marsh near its outlet, have marl along their course.

§ 20. Onekama.

Portage Lake (Fig. 14), on which is situated the Town of Onekama, is about eight miles north of Manistee and opens by a short but very navigable channel into Lake Michigan. It is surrounded by high hills on all sides and on account of the deep depression made by the lake the springs which issue from beneath the hills are numerous and large. One spring contained a considerable percentage of sodium carbonate, but the marl in the immediate vicin-

*This is a marl containing over 5% of clay and running rather low in carbonate of lime. After the organic matter is excluded the percentage of carbonate of lime amounts to 90.09.

†This is a sandy marl. Excluding the organic matter there is 81.65% of carbonate of lime.

ity in which the spring emptied showed no unusual trace of alkaline salts. This is only another illustration of the fact that the agency at work in the deposit of the marl has a power of discrimination, refusing certain salts from the water and depositing others. Such was shown to be the case of the sulphur and iron springs mentioned in the description of Big Whitefish Lake. Portage Lake is fed entirely by a network of springs and spring creeks and the water is very clear.

The shallows of the lake are not all marl. Strips of marl from three to four feet in thickness alternate with sandy beach around

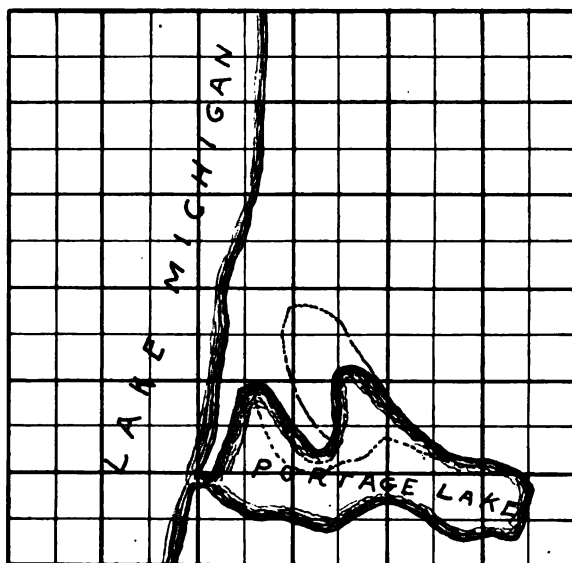


Fig. 14. Portage Lake, Manistee County.

the whole lake, but the deepest marl and that which engaged our attention lay to the north and northwest shores toward Lake Michigan. It lay in a lobe of the smaller lake forming its northwest corner and reaching beyond the water up to the low sand hills bordering on the Great Lake. It is only thought necessary to mention certain features which will illustrate the general ideas already gathered as to the location of marls.

As before stated the deeper marl was confined to the large lobe or lagoon of the lake. Lines of soundings were run in different directions and the following conclusions reached: The marl decreased in depth with increase in depth of water toward the center of the lake. There was also an increase of content of organic mat-

Agricultural College

Insoluble matter	above
Oxides of iron and aluminum	evenly
Calcium oxide (equivalent to carbonate)	21 to 22
Magnesium oxide	11el lines
Carbonic acid gas	h of marl
Organic and undetermined	ist named
	h the thick

Prof. J. Kleinheksel, Hol

Silica, SiO ...
 Alumina, Al,
 Iron oxide, Fe
 Carbonate
 Carbonat
 Sulphur
 Organ

ed with foreign
 ry small content of
 The ditches and small
 bed had carried down sand
 their immediate vicinity. The
 upper and salt sand which formed
 a basin or lagoon before mentioned
 aliar condition. The bed contained a
 ing organic matter alternating with the
 was well preserved and seemed to consist of
 marsh growth pressed firmly into a layer a foot or
 The layer was about fifteen feet below the sur-
 pure marl deposit.* Its presence might indicate that
 had ceased to deposit for a time, and with the return of
 conditions had again deposited, burying the layer of drift
 marsh growth which had accumulated.
 A part of the lobe examined was not under water at the
 A large part of it had recently been covered by water before a
 outlet into Lake Michigan had been dredged for the lake.
 When it was drained the surface of the marl had been left dry.
 This left the marl more or less dense and dry and as a consequence
 there was nothing but a slight growth of grass and the consequent
 "surface" was only a few inches to a foot in thickness. This was a
 great contrast to Rice Lake which had been drained about the same
 length of time, but was left very wet. The marsh growth had be-
 come luxuriant and the "surface" is from three to five feet of marsh
 growth. Beyond the dry portions of Portage Lake and forming
 the fringe of real marsh was the portion which had always remained
 wet. Here the growth of soil and roots reached five feet or more.
 From these comparisons it can readily be seen that it is impossible

*This may indicate a lower level for Lake Michigan at one time. L.

a marl bed from the depth of surface growth

are made varying from 13 to 22 feet. The
not including a large area along the
seven to ten feet. The marl is of
quality is shown by the following

	No. 1.
.....	2.81
.....	.65
.....	85.63
.....	3.08
.....	.014
Organic matter	6.96%

	No. 2.
Silica	3.64
Oxides of iron and aluminum	1.35
Calcium oxide	45.37
Magnesium oxide .....	.63
Carbon dioxide	35.86
Organic and undetermined	11.85

Submitted by A. W. Farr.

Samples No. 3 and No. 16, or Nos. 1 and 2 above, were taken at the respective depths of three and sixteen feet by the owner, Mr. Farr, and the latter was evidently mixed with sand as a careful examination of the whole basin showed no such amounts of sand, the sand being in all cases, excepting in the presence of flowing water, fine quartz sand and in small quantity. The remaining samples show a fair marl with no harmful compounds in proportions too large for manufacture.

CHAPTER VII.

MANUFACTURE OF PORTLAND CEMENT FROM MARL.

§ 1. Introduction.

The purpose of this chapter is not to give a full technical description of the process of cement manufacture. This may be found in any one of a number of large volumes written upon the subject.*

In a later chapter, prospecti from various cement plants in the State are cited and will furnish farther information. In order to connect these details and to give compact description of the process and to emphasize important points, this chapter is written.

§ 2. Definition of terms.

The name "Portland" was derived from the name of a popular building stone used in England at the time that our present cement was given its name. The cement was thought by some to somewhat resemble this natural rock, hence was named after it.

Portland cement is an artificial mixture of calcareous matter with silicious (generally clayey) matter, which is properly proportioned and burned to a point just short of vitrification or melting. The resultant slag will, upon grinding, set with the addition of water to form a cement.

Natural cement differs only from Portland cement in that nature has mixed the calcareous and argillaceous ingredients in nearly the proper relations.

Slurry is the properly ground and mixed clay and marl or limestone suspended in enough water so that the mixture can be pumped from one reservoir to another.

*See also 25th Annual Report of the State Geologist of Indiana; 22nd Ann. Proc. Ohio Soc. of Surveyors and Civil Eng., p. 18; 21st Proc. Indiana Eng. Soc., several papers; American Engineering Practice in the Construction of Portland Cement Plants, by B. B. Lathbury, 1902; A Rotary Cement Kiln for use in the Laboratory, by E. D. Campbell; Jour. Am. Chem. Soc., March, 1902; various papers, especially those by the Newberries in the Cement and Engineering News, and other pamphlets issued by the same press. Beside Lathbury and Spackman, Robert W. Hunt & Co., of Chicago, The Osborn Co. of Cleveland, and Hassan, Tagge and Dean of Detroit, may be mentioned as designers of cement plants. See also report by Prof. I. C. Russell in the 21st Annual Report of the Director of the U. S. Geological Survey.

The gradual perfection of Portland cement to-day is owing to the application of raw material and high grade machinery to the development of one chemical principle which is and will remain at the foundation of the cement industry, that two elements or groups, lime on the one hand, and silica or alumina on the other, when properly proportioned and intensely heated, have the power to combine with each other and then later with water such strength that after the combination once occurs, fire, water, acid or salts, have little power to disturb them or weaken their hold upon each other. The first group is calcareous. We see it purest in lime or calcium oxide, in an amorphous rock as calcium carbonate of limestone, as calcium carbonate in chalk, and in the purest state as crystallized rock or marble. The second group is silicious. This forms a large part of the earth and is found purest in quartz sand and fire clay. When these two groups, the calcium carbonate of the marl on the one hand, and the silica and alumina on the other, are finely ground and mixed and subjected to a temperature of between 2,000 and 3,000 degrees Fahrenheit, the calcium carbonate loses its carbon dioxide becoming calcium oxide and the silica becomes soluble. When the slag is ground to powder and mixed with water the nascent compounds recombine to form a tricalcic silicate and aluminate, an insoluble, non-combustible rock which becomes harder if anything, with age.

§ 3. Historical.

Before the discovery of the principles which govern the setting of cement, the Romans and they who followed them used slaked lime and a volcanic dust called pozzuolana. It contained the above mentioned substances in the right proportions to form a fair cement.

About the year 1756, Smeaton, an English engineer, made experiments to find a mortar which could be used under water in the construction of the Eddystone lighthouse. About the year 1818 Pasley in England and Vicat in France began experimenting upon cement materials to ascertain the proportions necessary to produce an artificial cement.

"In 1824 Joseph Aspedin, a bricklayer of Leeds, discovered and patented a method of making a hydraulic cement and named it 'Portland,' from its fancied resemblance in color and texture to

the oolitic limestone of the Island of Portland, well known and in great favor in England as a building stone."

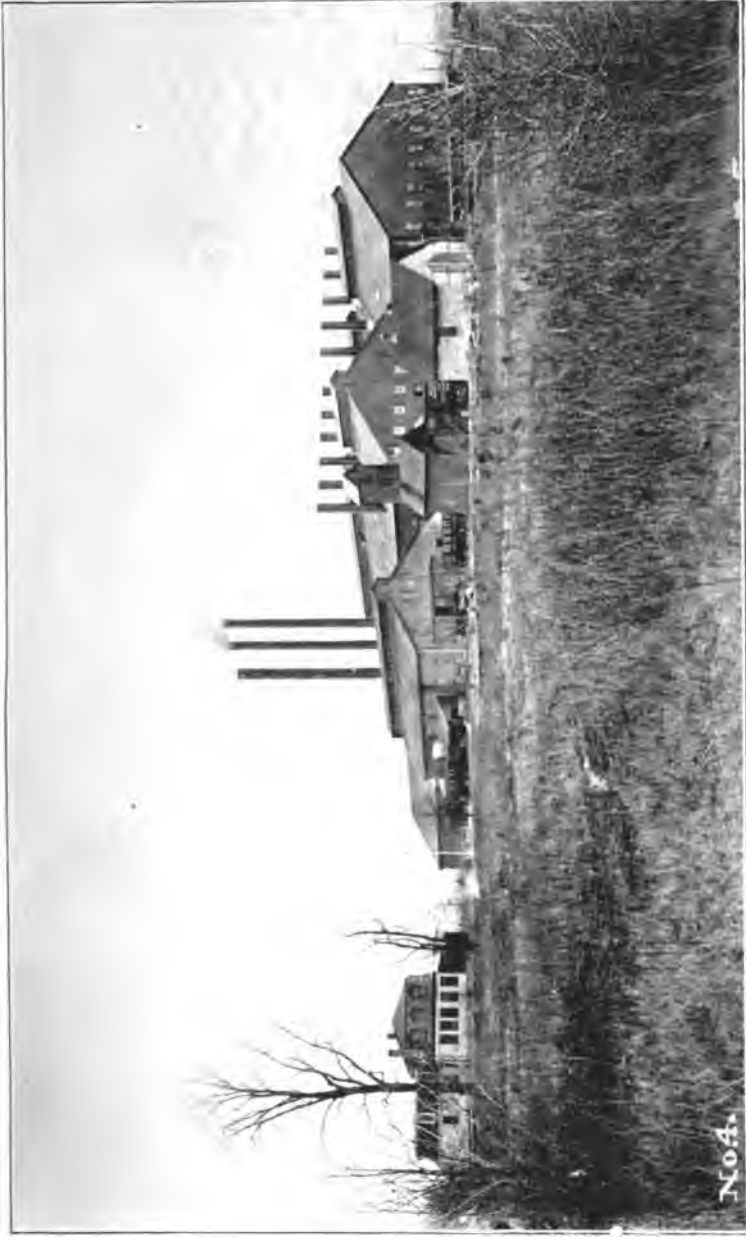
§ 4. Materials for Cement.

It will not be of profit to follow the development of natural cements. They are produced by grinding and burning a rock having cement materials in nearly the right proportions mixed to some extent by nature. As the proportions always vary the product is more or less unstable, is liable to crack and warp more than Portland cement and never stands as high tensile tests. It is therefore untrustworthy in those portions of great engineering works where great soundness and durability are required. It is produced more cheaply than the Portland cement and is very satisfactory for low grades of work. It is manufactured in large quantities in the United States and supplements largely the use of the more costly Portland cement. As the State of Michigan is supplied with extensive deposits of marl and clay suitable to the production of the highest grade of artificial or Portland cement it is well to notice the different ways in which material and machinery are manipulated to produce the same result.

It is a common idea that but one or two materials may be used for the production of cement, but this is erroneous. Anywhere where lime and clay constituents can be found sufficiently near each other and pure enough, Portland cement may be manufactured. In England, much of the cement is made from chalk, which is a calcareous formation similar in composition to marl, but dry, and a dense blue clay. In the United States chalk is used so far only at Yankton, S. D. Limestone and clay are the favorite materials in most parts of the world and it is only within the past few years that marl and clay as raw materials have come into any great prominence.

Several methods of burning and mixing the raw materials are used in Europe and the United States, adapting themselves somewhat to the nature of the raw materials used.

In England, in the Medway district on the Thames, marl and clay are ground and mixed with 120 per cent to 140 per cent of water. The finer particles are then flushed off by water passed into "settle backs," where the mud settles and the clear water is drawn off. When this sediment has dried to the consistency of a paste, it is gathered up and deposited on floors where it is dried still more rapidly by waste heat from the kilns. It is then mixed with



GENERAL EXTERIOR VIEW OF AN ELEVEN KILN PLANT.

charcoal and burned in kilns. The remarkable feature about this method is the thorough manner of mixing. It is the most thorough method known as the particles of clay and calcium carbonate are suspended together in water and allowed to settle somewhat as in a natural sedimentary deposit. It requires a month to dry the material, and the method is therefore too costly in time and is giving way to more rapid methods.

Mixing by the semi-wet process is probably most widely used throughout the world. When limestone and clay are used they are mixed with about 30 per cent or 40 per cent water, by means of sludge mills or similar contrivances. The mixture is then ground, passed to a drying floor, subjected to waste heat from kilns and burned as before. The mechanical mixture of the particles is not as perfect as in the first method but the drying occupies but 20 hours.

Sometimes the materials are mixed nearly dry and formed into bricks which are burned as before, with coke in a kiln. This is done in the dome kiln or dry method, which has been used to some extent in our own State at Union City and Kalamazoo, and will be described later.

The method of burning differs somewhat. Where a dome kiln is used the layers of mixed cement material alternate with layers of charcoal. In the continuous kiln, charcoal and unburned and partly dried cement materials are fed in at the same time at the top and the whole ignited at the bottom. The portion of heat not used in burning the cement at the bottom escapes upward and helps to raise the temperature of the half wet material above. In this way much more heat is said to be saved than in the dome and rotary kiln process.

Cement could be manufactured using sand to furnish the silicious elements instead of clay. Briquettes of cement made in this manner seem to have stood very good tests. Yet in practice, sand in any form is dreaded in cement manufacture, from the fact that it is so expensive to grind it to a sufficient degree of fineness for the purpose. The clay* is preferred instead because it is divided much more finely than sand, being already ground on account of the breaking down processes of nature.

It can be readily seen that the materials used and the processes relied upon vary widely in different districts although the finished

*What is commonly known as clay is often very largely only extremely fine particles of quartz, mineralogically the same as common sand. L.

product must be almost the same in all cases, as Portland cement has a narrow range of standard composition, which must be approximated in all methods of manufacture. The process used in Michigan depends mostly upon the materials at hand. The silicious element used is either a surface sedimentary, or a shale clay, depending upon which one having the best composition is at hand. The method of burning in nearly all cases is the rotary kiln process. There are few lakes or marshes that can be sufficiently drained so that the marl can be treated by the dry or semi-wet process and for this reason a more detailed description of the rotary or wet process will be given. From the foregoing it must be clearly understood that the factories of Michigan have not only to compete with those using their own process, but also with the remainder of the manufacturies by the limestone process, which alone furnishes more than half the cement produced in the United States. It must always be borne in mind that 40 to 60 per cent of the marl is water and nearly a half of the remainder carbon dioxide, a gas which is driven off in burning. The cost of handling and drying this great bulk of material must never exceed the cost of quarrying and grinding the limestone. When this happens, Michigan factories will be undersold by those of the limestone district. Besides this competitor there is the natural cement. This will take the place of Portland cement in many cases where the price of the better cement rises too high.

§ 5. Kiln process of cement manufacture.

The two methods so far employed in this State are the dome kiln and the rotary process. The former of these two processes is fast going out of use in this part of the country as it does not seem to fit the materials used as well as the rotary process. In 1872 a plant of this kind, the first cement plant in Michigan, was started at Kalamazoo. The marl beds which were used are described in Chapter VI. Another plant of this kind is erected at South Bend, Indiana, but was not in operation when visited. The process which was employed at Union City, Michigan (See Plate III), may be briefly described, as follows:

The marl was scooped up wet from the marsh and is thoroughly mixed with dry clay. The mixture, now of a doughy consistency, is pressed through a square orifice and is cut about the form and size of building bricks. These marl clay bricks are laid on flooring

of T rails to thoroughly dry, when they are then ready for the burning, which is accomplished by kilns.

A kiln resembles a mammoth hollow cigar, cut off at both ends. It is built of fire-brick, and is about forty feet high by eight to ten feet in diameter. Beneath is a fireplace of about five feet to furnish a thorough circulation of air.

At the base of the kiln, above the open air space, an arched layer of these bricks is packed, a layer of lumps of charcoal, then another layer of bricks till the kiln is one-third or one-half full. The mass is then fired, and burns for about forty-eight hours; the bricks fuse into lumps of heavy, black slag, perforated by the exit of the carbon dioxide, which is expelled by the fierce heat. The whole mass shrinks and collapses and cools, and is then raked out. Then the slag is sorted by hand into two grades of cement, and is ground by mills into fine, dark brown powder which we know as Portland cement. This is an extensive process, requiring large buildings for drying, many kilns for burning (for a kiln burns only seventy-five barrels at a time) and many men to transfer and sort.

This process is not as exact as it should be. Part of the bricks are overburned and part underburned and must be sorted by hand, requiring great expense in time and labor. It has been displaced at Union City by the rotary process, and all the new factories in the State are employing the latter.

§ 6. The rotary process.

The rotary process, in order to be successful, should be carried on upon a large scale. The buildings which protect such a factory generally cover several acres (Plate IV). The prevalence of disastrous fires which have wiped out several large factories in the past year, causing great delay in the work as well as the financial loss, should emphasize the construction of durable and fire-proof buildings. The latest are being built largely of steel and cement. The machinery is so grouped (Plate V), that the raw material is transferred by machinery from one step of the process to the next, till it enters the storing bin a finished cement. The following is a brief description of the whole process, as seen at Bronson, Michigan.

The marl is scooped up by an ordinary dipper dredge and is drawn a few hundred feet to the factory on small dump cars, where

- it is stirred and screened and then pumped into a large funnel to measure it.

Meanwhile, the clay, which is mined several miles away and drawn to the works by rail, is elevated to the second story by machinery, is weighed by the wheelbarrowful and dumped into a hopper which drops it to a cluster of revolving millstones, which at the same time receives the semi-liquid contents of the huge marl funnel. When both have been ground and mixed with each other, this mixture drops into a second reservoir, where it is thoroughly stirred and mixed for some time by revolving paddles. From this reservoir the mixture, now termed slurry, is pumped into huge tanks, where it awaits the burning process.

Grouped with each tank is a huge cylinder about 40 feet long and four or five feet in diameter. The cylinder lies with the end that is farthest from the tank a little below the horizontal. The end opposite the tank is closed by a cupola.

The cold, wet slurry flows in at the tank end, the whole cylinder revolves, and the liquid mixture, caught on its inner surface, runs slowly towards the cupola at the further end. Here a falling stream of crude petroleum is ignited and blown by air blasts into the end of the cylinder. The solid sheet of flame penetrates six or seven feet, being under control. The slurry, slowly approaching, is first dried, then heated, and by the time it reaches the end of the cylinder is fused into liquid nodules about the size of pebbles, and falls through a slit at the base of the cylinder. Here it is received by an endless chain of wheeled trays, and, having cooled, is borne to the mills. These mills are very efficient, grinding it to a powder, ninety-nine per cent of which will pass through a sieve with 10,000 meshes to the square inch. It is then finished cement and is stored in bins. In this process, as in the kiln process, the fine powdering and mixing of the crude material is carefully accomplished, and, by burning, the carbon dioxide is driven off and the mass thoroughly fused. This process is almost entirely accomplished by machinery. The machinery is expensive, but only requires the labor of fifty men to run the whole plant.

It is economical, as the burning is performed with exactness, and there is no charcoal to fuse with, and impair the strength of, the cement, nor is any hand sorting necessary.

In the latter case the quality of the cement and cheapness of manufacture is unrivaled.

§ 7. Preliminaries.

1. *Digging.* The raw material, marl, is in nearly all cases found in a lake or a swamp or both. In this condition it may be covered by a few inches to several feet of water, may be bare, or be covered with a surface of grass or rushes which must be "stripped" before the marl can be dug.

In many parts of the State there are extensive marshes covered with a growth of timber which must be cleared and grubbed before the marl becomes available. In such cases it is noticed that nearly all the roots follow the moist surface of upper soil which has been deposited on the marl, and do not penetrate deeply. This renders clearing much less expensive and the clearing can nearly all be done by burning. It is best in selecting sites for factories to avoid as much as possible the marl lands covered with a thick surface of swamp growth or forest. There is much marl land available in the State that does not require expensive surfacing, which should be chosen in preference to the less available territory.

The content of moisture will often vary much according to the position of the marl below or above the water line of the lake or marsh. In the same lake basin there may be marl in mid-lake containing 60 per cent to 75 per cent moisture, and at the same time marl on higher marsh land at the sides, which will not contain over 25 per cent.

The expense of surfacing is of course somewhat governed by the thickness of the bed and the depth to which it may be dug or dredged. A bed ten feet thick will be much more wasteful in digging than one thirty feet thick, for in each case the surface soil or growth is mixed with the marl in dredging, and must be burned out in the rotaries, involving cost of fuel in drying and time in handling the surface material, which is in the end burned, forming only an ash. Not only is there expense in handling and burning the material that becomes mixed with the marl from the surface, but also there must be a certain margin or remainder of the marl at the bottom of the bed which cannot be dredged on account of admixture with sand or unsuitable clay, of which the true bottom may be composed. It can then be easily seen that there is a greater proportion of the marl in a thick bed, available for use, than there is in a thin deposit, for the waste must be the same in both cases. With the present large supply of deep beds

the shallow deposits will not be immediately used. If there are but a few inches of grass and loam above the marl, no appreciable cost will be incurred, excepting to increase the organic content of the upper scoopings of the dredge. If there are several feet of dense marsh growth, sometimes as high as six, it may cost \$75 an acre for surfacing,—quite a handicap.

2. *Draining.* In many lakes it is found expedient to drain by a short channel and thereby lower the water level, bringing the deeper parts of the lake within working depth of the dredge. Not every lake is located so as to be easily drained. Also it will be found, if attempt is made to so utilize marl that has laid at any great depth under water, that the quality of such marl will be much poorer, being higher in organic matter and lower in the essential calcium carbonate.

When the lake or marsh has a level of several feet above the stream or lake which empties it, it may be possible to drain it so that the semi-wet or even dry method of mixing may be used. This was to have been done at Watervale and was contemplated by the Hecla Cement Co.

3. *Dredging.* On account of the semi-fluid condition of most of the marl of the State, and its location partly in or adjacent to water, the easiest method of digging the marl has been by the ordinary steam "dipper" dredge. This is a barge or scow floating on the water and operating a large scoop or dipper, which can work to a depth of about twenty-two feet, as was claimed at Bronson. The rubbish or surface growth of a marsh is piled to one side, and the dredge makes a channel for itself as it digs the marl. It can be seen that this method is best adapted to the greater part of the marl in Michigan, which lies either under water in shallows or flats or in a marsh which is at or near water level.

Another proposed machine may come into general use. It is also built on a scow and consists of a movable crane carrying an endless chain of buckets. This chain can be lowered to greater depths by the crane and will perhaps be able to dredge to a depth of thirty feet, though, as the quality of marl decreases and the expense of power in digging will rapidly increase with great depths, it will not be found economical to dredge to the bottom of deep beds. In many factories in the State the marl is dredged and then piped to the factory.

There is one more method of transporting the marl. This is by digging or dredging and then pumping to the factory.* When the marl is pumped it must be mixed with slightly more water, which must in turn, be dried out in burning in the rotary. The increased expenditure for fuel will likely offset the cheaper transportation. The pumping plan is only considered where the marl is adjacent to the factory. Where the marl is several miles away,† a railroad must, of course, be employed, as hauling by wagon is entirely out of the question as being too expensive. Where it is near, an overhead trolley bearing cars or a narrow guage road, in which steam or horses are the motive power, can be used.

Clay must be quarried or dug according as it is a shale or a clay. For quarrying see the account of Bronson in Part I, and elsewhere in this report. Out of 14 factories where the raw material could be located, all but one had the marl deposit within two or three miles of, or directly on the site of the factory, while but four had their clay near the factory, most of them getting it long distances away, in some cases in Ohio‡ or Indiana. The estimated cost of putting the material at the factory therefore, varied from eight cents to seventeen and one-fifth cents per barrel of finished cement, being greatest in the case of the Hecla works, who were to transfer their marl about thirty miles from bed to factory site.

§ 8. Estimates on raw material.

One factory in the State was running about 2,000 pounds of marl to the cubic yard, while it was said to require one and one-half cubic yards of liquid marl to a barrel of cement.

Now a barrel of Portland cement weighs 380 pounds. An average of 65% of this is calcium oxide; 65% of 380 equals 247 pounds of calcium oxide required for a barrel of cement.

Taking a wet marl, which has 40% moisture, and 90.3% calcium carbonate in the dry residue the available calcium oxide would figure as follows:

100% less 40% equals 60% dry matter.

90.3% of 60 equals 54.18% calcium carbonate.

100% calcium carbonate less 44% carbon dioxide equals 56% calcium oxide.

56% of 54.18 equals 30.3% of original weight as available calcium oxide.

*As at the Woodstock and other plants.

†As is the case in the Hecla Plant at Bay City, 30 miles from the bed.

‡Millbury.

At the above factory estimate of raw material $1\frac{1}{2}$ cubic yards of marl would weigh:

$1\frac{1}{2}$ times 2,000 equals 3,000 pounds.

30.3% of 3,000 equals 909 pounds available calcium oxide, whereas it really furnishes but the 247 pounds necessary for the barrel of cement. This means that the deposit which was worked must have had a higher content of organic matter and moisture than we have assumed.

Notice the effect of increased per cent of moisture and decreased percentage of calcium carbonate on the percentage of available calcium oxide. Take for instance a marl 60% moisture and 75% calcium carbonate.

100% less 60% equals 40% dry matter.

75% of 40 equals 30 of original weight as calcium carbonate.

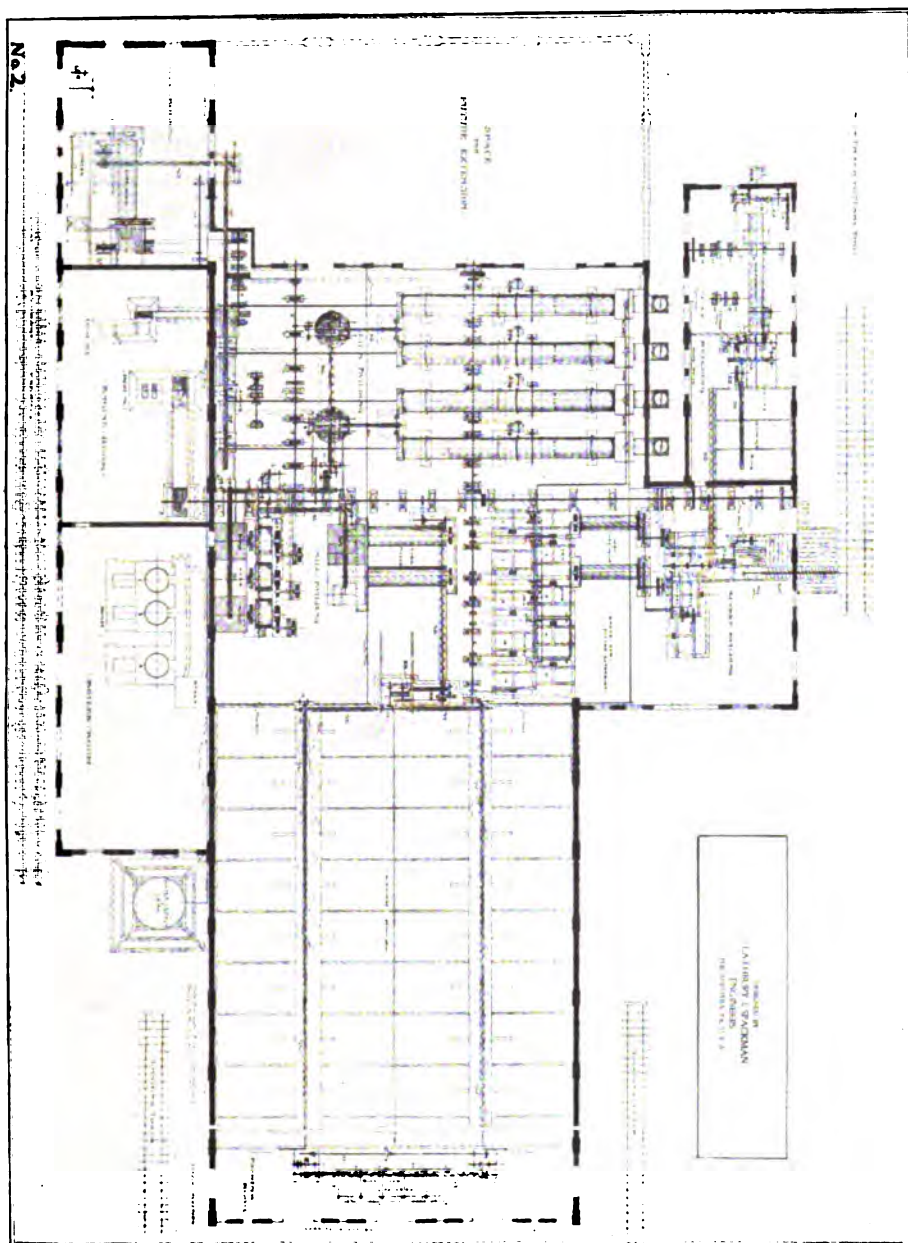
56% of 30 equals 16.8% of original weight as available calcium oxide.

In this case but 16% of the original weight of the marl as dredged and transported to the factory, contributes to the active elements of the cement. It can thus be seen that the actual supply of raw material is greater or less per acre, according to the condition in which it may be found.

No exact volume of marl to the barrel of cement can then be given, as it varies in each bed, but for a high grade marl of medium moisture, probably 10 cubic feet to the barrel would be an average. It is *estimated* in the Clare bed with 94% to 96% calcium carbonate, and 50% to 70% moisture to be from 7.5 to 12.5 cubic feet. At Zukey Lake, the Standard Portland Cement Company, with calcium carbonate 93.92%, estimates 9 cubic feet of marl to the barrel of cement.

The clay is much more compact and free from moisture. The volume of clay of the Omega Cement Company required for one barrel of cement was estimated to be 1.12 to 2.12 cubic feet, according to the per cent of calcium carbonate contained in the clay.

The question as to the requisite acreage of marl is discussed by several cement plants, and the estimated acreage varies widely, being from 262 acres to 2,000 acres. The favorite plan is to show an acreage which will run a factory of the desired size for 100 years. Several factories have been projected upon 75 or 100 acres, but have evidently given up from lack of material.



GENERAL PLAN OF FOUR KILN PLANT WITH PLACE FOR EXPANSION

§ 9. Requisites for marl deposit.

Taking the consensus of opinion as laid down in the prospectuses of the different factories built or building in the State, and the relative merits of beds as viewed in various parts of the State, the requisites of marl are as follows:

Surfacing.

There should be little or no surfacing and the water covering the marl should be as shallow as possible, not over six or eight feet. The amount of raw material in the State does not necessitate the use of beds covered with any great depth of muck or other useless matter which requires surfacing. The marl must be located on or near railroads, but better than all, on the Great Lakes. See freight rates, under shipping.

Necessary composition.

The prospectuses so far examined do not give any analyses of marl lower than 90% calcium carbonate. They vary all the way from this to 96%. It is doubtful in some cases, whether this is the highest sample found, or the average of samples in the bed. One prospectus which gave a sample analysis in its prospectus of 95.73% calcium carbonate gave in two samples taken and analyzed by two reliable chemists, when its bed was sampled as fairly as possible, 83.04 and 77.05% calcium carbonate respectively. In the majority of beds the marl varies with the depth, and when it is 90% CaCO_3 , near the surface it is likely at 20 or 30 feet to be only 75 or 80% calcium carbonate, as explained in previous chapters.

It is very safe to say that if an average of all samples taken, whether deep or shallow, and irrespective of the choicest location, reaches 90%, the bed is safe as regards calcium carbonate. This will imply unless the bed is exceptional, that many samples will run as high as 95%.

Depth.

The depth of marl used or counted upon in the State varies from as low as 15 feet to depths which no scow of the present kind in use could possibly reach. It is fair to say that marl seems to be used anywhere from 15 to 25 feet below water level, with the restrictions as to water mentioned in the paragraph on surfacing. Low calcium carbonate means high organic matter, which is undesirable from the greater bulk of useless matter transferred to the factory to be burned.

The dangerous constituents are sulphuric acid and magnesia.

Sulphuric acid.

This does not appear to be troublesome according to the analyses seen in the various prospectuses, being given from .08% to .58%. It could go considerably above this, depending upon the amount in the clay. It is not often very troublesome in pure marls, but should be watched.

Magnesia.

This is very much more troublesome, as a strain of magnesian clay in the marl may cause it to vary dangerously. The cement prospectuses giving analyses, show from 1.41% to 1.79% magnesium oxide, which is a very safe limit.

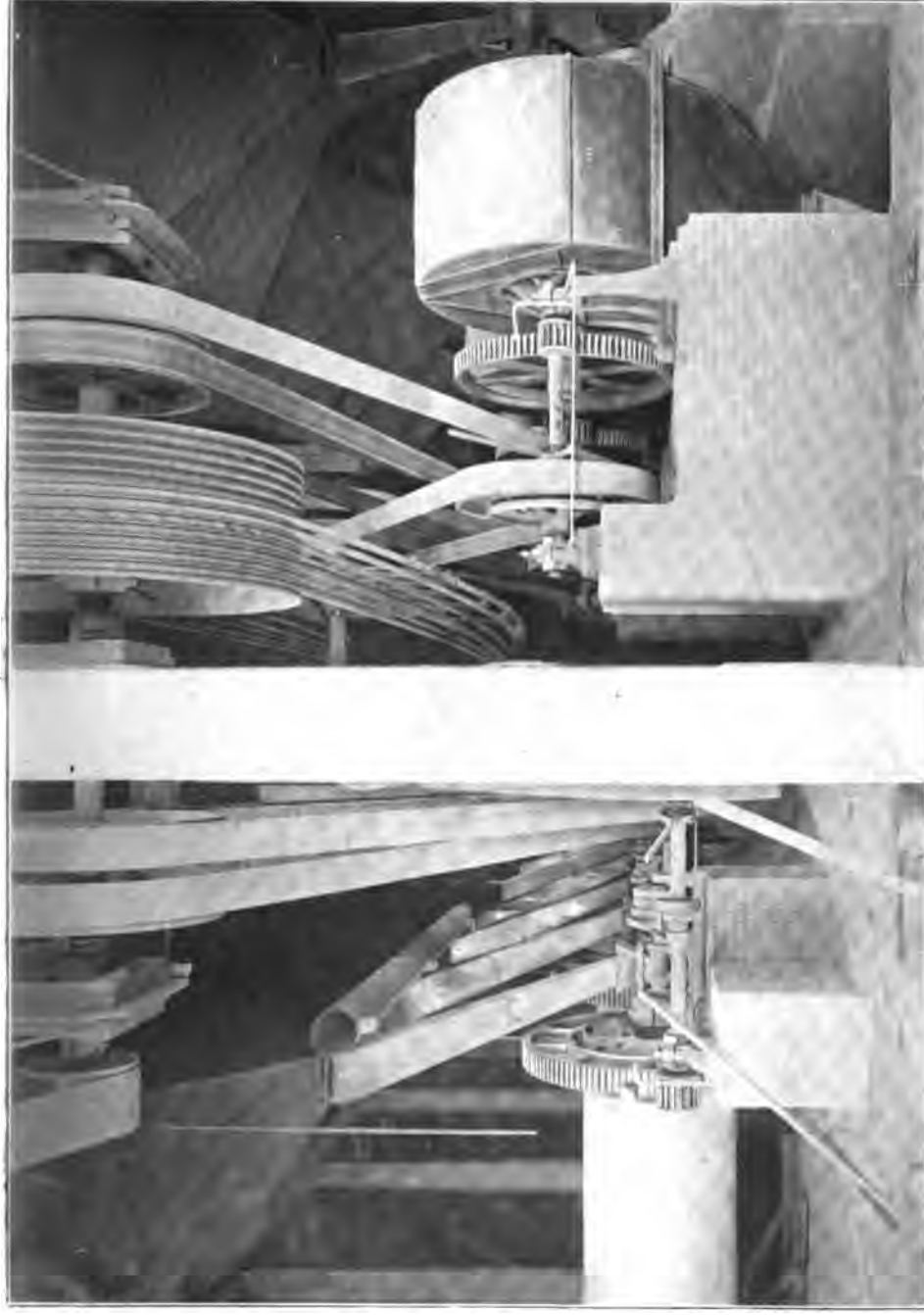
Grain.

Some of the marls of our State are very fine and rival the finest grinding of any material by machinery. One case was noted where there was but 4% left on a 200x200 sieve, or 40,000 meshes to the square inch. This is certainly wherein marl excels all other raw materials for cement manufacture. It need hardly be said that an excess of shells or pebbly accretions somewhat increase the power necessary to grind finely and are a drawback. A marl with above 3% or 4% coarse or fine sand, must be ruled out. Effects will be noticed further on. For analyses of marls for factory purposes, see p. 32 and the descriptions of different plants.

§ 10. Clay.

We have in this State two kinds of clays, one being shale, which is often very hard to grind, but is steady in composition, and generally most free from carbonates. The other class are not of the nature of rock, but have been more recently laid down by the action of water and are not compressed. The grains are more easily separated, and grinding is effected with less cost in power. A good cement clay analysis is that of Millbury, O., being the average of 50, as given by J. G. Dean; SiO_2 61.06, Al_2O_3 18.10, Fe_2O_3 6.65, CaO 1.25, MgO .53, SO_3 1.05, organic matter and water 9.20.* The principal points about clays are the relations of silica and alumina and the proportions of lime, magnesia and sulphuric acid. If there is much lime the clay will not go as far with the same amount of marl. Hence, if it is to be carried by railroad any distance, there is the resulting disadvantage of increased cost of transportation. Organic matter and moisture are of course a dead weight. The above clay is a

*See also Prof. Fall's paper.



GENERAL INTERIOR VIEW OF SLURRY DEPARTMENT.

fairly good sample of surface clays used for cement manufacture, the same bed from which this was taken, being used by two factories in this state. A surface clay, if of the right composition, is much better because easier to dig and grind than shales. Often in the neighborhood of shale outcrops there is found a good surface clay, which is the broken down and decomposed shale, and makes a very suitable clay.

The great body of Michigan clays are too high in magnesia and in alumina in proportion to silica.*

An average result from six factories giving their clay analyses was the following analysis:

Silica, 59.90.

Alumina, 22.76.

Magnesia, 1.47.

Sulphuric acid, 1.04 (but two out of six stated).

§ 11. Admixture of raw materials.

This of course depends upon the exact amount of moisture and the percentage of calcium oxide in the marl, on the one hand, and the percentage of silica, iron and alumina in the clay, on the other. It can never be correctly determined without a careful analysis of both raw materials. A good clay is less variable than the marl. At Bronson, it was said that the clay was analyzed once a week and the marl was analyzed every day. The slurry is analyzed frequently to see if it continues in the right proportions, showing at once whether the measurement of the raw materials is carried on exactly and whether the raw material is varying much from the last analysis. If it does, one raw material or the other must be added to preserve the correct balance for the production of a cement of even composition.

Lathbury and Spackman, who write the article on cement making given below, say in their magnificent triglot on American Engineering Practice in the constructing of Rotary Portland Cement Plants:†

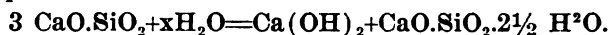
"A glance at the analyses of the standard brands of cements, both American and Foreign, will show a great uniformity, and it can be stated that in a good cement, the amount of the different ingredients will only vary within very narrow limits, as shown in the accompanying table.

*See Part I of this volume, i. e., Ries' report on shales and clays of Michigan, and the analyses of shales in the descriptions of various plants.

†Published by G. M. S. Armstrong, Harrison Building, Philadelphia.

	Minimum.	Maximum.
Silica	19%	26%
Alumina	4	10
Iron	2	5
Lime	58	67
Magnesia	0	5
Sulphuric Acid	0	2.5
Alkalies	0	2.8

Le Chatelier, after long study of the composition of cements, concluded that the two important compounds existing in the clinker were a tri-calcic silicate ($3\text{CaO} \cdot \text{SiO}_2$), and a tri-calcic aluminate ($3\text{CaO} \cdot \text{Al}_2\text{O}_3$). The hardened cement consists of hexagonal plates of calcium hydrate $\text{Ca}(\text{OH})_2$ imbedded in a white mass of interlaced crystals of hydrated calcium mono-silicate ($\text{CaO} \cdot \text{SiO}_2 \cdot 2\frac{1}{2} \text{H}_2\text{O}$). The chief reaction which takes place during the setting of cement, according to Le Chatelier may, therefore, be represented as follows:



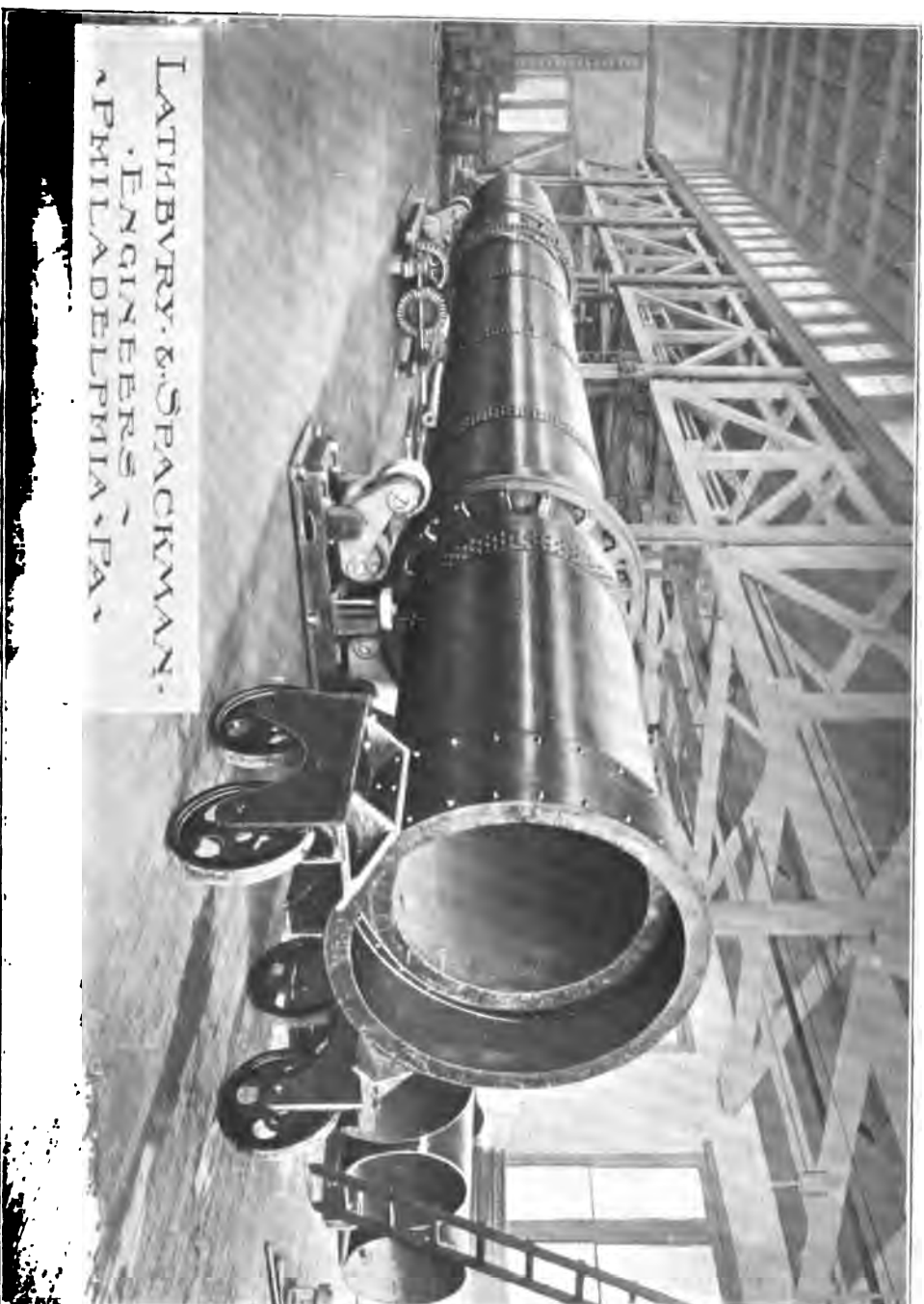
Assuming that three equivalents of lime and no more can enter into the combination with silica and alumina in a cement, then assuming magnesia to act the same as lime, the proportion of lime should not be less than that required by the formula $\frac{\text{CaO} + \text{MgO}}{\text{SiO}_2 + \text{Al}_2\text{O}_3} \cdot 3$

or greater than $\frac{\text{CaO} + \text{MgO}}{\text{SiO}_2 + \text{Al}_2\text{O}_3 + \text{Fe}_2\text{O}_3} \cdot 3$

"The Messrs. Newberry in a series of researches as to the constitution of cement, determined by synthesis:

"First, that lime can combine with silica in the proportion of three molecules of lime to one of silica ($3\text{CaO} \cdot \text{SiO}_2$) and give a product of practically constant volume and good hardening properties. With more than this proportion of lime the product is not sound.

"Second, that lime can combine with alumina in the proportions of two molecules of lime to one of alumina ($2\text{CaO} \cdot \text{Al}_2\text{O}_3$) giving a product which sets quickly, but shows constant volume and good hardening properties. With more than two molecules of lime the product is not sound. Thus Newberry gives as the formula for a cement with the maximum amount of lime, $x(3\text{CaO} \cdot \text{SiO}_2) + y(2\text{CaO} \cdot \text{Al}_2\text{O}_3)$ x and y being variable factors, dependent on the relative proportions of the silica and alumina in the clay.



VIEW OF ROTARY.

1

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"In practice, cements contain a slightly less quantity of lime than the above formula requires, because of the difficulty of securing perfect mixing and burning and the danger of over liming if the formula is exceeded."

§ 12. Mixing and raw grinding.*

The marl is dumped into a large tank or vat and is generally screened to relieve it of gross organic and foreign matter, useless to the process. As before mentioned it may arrive at the factory in little dump cars, by means of an overhead trolley or cable working from factory to bed, by horse or mule power, by scow towed in the lake, or by pumping from the dredge where it is scooped up directly to the factory by pipe. In all but the last method the marl becomes somewhat dried during transportation. The marl may be pumped into a large hopper and estimated by volume, while the clay is weighed directly, the right weight of it being added to each hopper of marl, when the two are then mixed and ground together. Sometimes the clay and marl are said to be ground separately. At Bronson, millstones were used to grind the raw materials in the wet, and at Omega they were ground as a slurry in tube mills (Fig. 15). The devices used to handle the raw

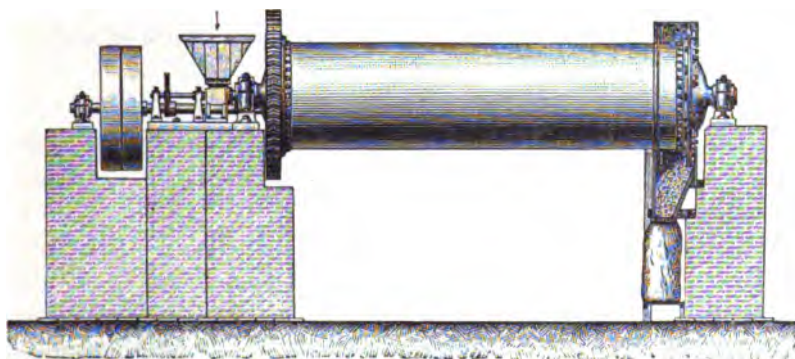


Fig. 15. Tube mill.

materials at this stage of the process vary much. The idea should always be to handle the resulting slurry with as low a percentage of water as possible and yet make a perfect mixture of the two materials. Screw conveyors and sludge mills are used for mixing and conveying from vat to vat and to the tanks which supply the rotaries. The slurry in the tanks must be kept in motion as it is

*See Plates V, VI, and IX.

fed out, because the more solid material settles by gravity to the bottom and would, if allowed, disturb the equality of the mixture.

The expense of the raw grinding department was estimated for a 2,400 barrel plant at Lupton, as follows:

Raw grinding department (two shifts).	
2 millers at \$2.00.....	\$4 00
4 scalemen at \$1.50.....	6 00
1 electrician.....	1 75
Oil and grease.....	3 00
Total	\$14 75
125% repair account.....	18 44
Grand total.....	\$33 19
Cost per barrel 1.4 cents.	

Other plants, planned to manufacture from 600 to 1,000 barrels, show four to six cents cost per barrel for this step. No expense should be spared to do this step thoroughly. The whole success of the process depends upon the fineness of grinding and intimate mixing of every particle of clay and marl so that each particle of silica and alumina shall have its portion of calcium oxide ready to satisfy it. The larger the lumps of raw material left unground, the more unsatisfied and harmful material remains.

§ 13. Burning.

Every factory now going or projected in this State uses the Ransome rotary kiln process (Plate VII of Lathbury and Spackman's illustrations). It was invented by F. Ransome, an English engineer.

"It consists essentially of a revolving furnace (cylindrical in form), constructed of an outer casing of steel boiler plate lined with good refractory fire brick, so arranged that certain courses are set forward in order to form three or more longitudinal projections, fins or ledges. The cylinder is rotated slowly by means of a worm gear and wheel driven by a pulley upon the shaft carrying the worm. The cylindrical casing is surrounded by two circular rails or pathways, turned perfectly true, to revolve upon steel rollers, mounted upon suitable foundations. Gas, oil or pulverized coal may be used for fuel."*

The kilns are usually arranged in a row (Plate VIII), with the

*Cement and Engineering News.

supply tanks or reservoirs back of them. The kilns lie side by side with their longest axes parallel so that the motive power may be applied over as small space as possible. In a fourteen rotary plant as at Coldwater or Quincy, there are two rows of rotaries, seven kilns each with the rows facing each other. Petroleum, gas or pulverized coal is used as fuel. This depends somewhat upon which can be delivered most cheaply at the factory. The price of petroleum, of course, is in the hands of a few and is liable to vary more or less, while coal may be had on the grounds in many parts of the State. It is therefore coming into use more generally. According to Stanger and Blount, its ultimate success is dependent upon the method of injecting the stream of coal dust into the rotaries.*

The Ransome kiln has been modified much to get around some of the difficulties encountered, and has been used with success in America, though it proved unprofitable in England. The chief trouble in the wet process, as employed in nearly all the factories in this State, is the cost of fuel. This is considerably greater than it should be when the actual heat is figured out theoretically. The weight of coal necessary to be consumed to produce clinker has been estimated as 23.28% of the weight of the clinker produced. If a portion of the heat of the waste gases is used and they are allowed to escape at 200 degrees C., the percentage is reduced to 17.1% of the weight of clinker in coal. In wet process, 40% moisture, with escaped gases at 200 degrees C., 49.3% of the heat is required to dry the mixture.*

The upper end of the kiln is metal while the lower end toward the flame is lined with magnesia or aluminum brick, to withstand the great heat. While the bricks are as nearly pure as possible, the lime of the slurry acts upon them, producing fusion to such an extent that it has been estimated† that three kilns did about the work of two, because of the break downs and delays caused from the fusing of the lining. A way is suggested and looks very feasible, of lining the fire brick with a coating of cement, packing it down so as to afford a protection to the brick below. This method is employed at the Atlas Cement works as described by Stanger and Blount.

*Engineering News, October 24, 1901.
†A. H. Cederberg.

Analysis of kiln brick, Stanger & Blount.

Silica	55.82%
Alumina	37.98
Ferric oxide	4.02
Calcium oxide	
Magnesia .....	.78
Soda .....	.88
Potash .....	.37

In the furnace the slurry is first dried, then as it travels further toward the flame the different materials become oxidized. The 50 or more per cent of water is driven off in the form of steam. The organic matter is reduced to ash, the carbon being driven off in the form of carbon dioxide. The calcium carbonate loses 46 per cent of its weight as carbon dioxide driven off as a gas. The silica and alumina are made soluble and brought into a nascent condition with the calcium oxide. If there is much sand in the slurry, it is not as easy to grind nor as likely to be ground fine, and the sand, resisting the heat, delays the point of semi-vitrification and increases the cost of burning besides being hard to grind at any stage of the process.

As the heat necessary to clinker cement material is between 2,000 and 3,000 degrees F. the blast of air coming in with the coal or petroleum and the gases driven off, must carry with them an immense amount of heat.

The amount of heat necessary to produce clinker for one barrel of cement is estimated by S. B. Newberry as follows:

Intermittent or vertical kiln (coke)	76 to	95 lbs.
Continuous vertical kiln	42 to	46 lbs.
Rotary kiln, dry material	110 to	120 lbs.
Rotary kiln, wet material (50% water)	150 to	160 lbs.

It is also estimated by Fred W. Brown, E. M.* that an additional 3 gallons of oil or 30 lbs. of coal is consumed where wet material is used in a rotary kiln instead of dry. These figures tally rather closely and show the increased expense at this stage of wet marls over dry limestone as a raw material. In case the marl contains a large per cent of organic matter this is nearly as expensive as water because it calls for a large draft of cold air which must be heated to the furnace temperature in oxidizing the useless organic matter. The question is then, how to utilize the immense amount of heat which is wasted. This is roughly estimated as of 175 horse

*Cement and Engineering News.

power intensity when but about 100 horse power of energy is used in clinkering the material.

Mr. Brown makes the following suggestions for improvement.

1. Recovery of heat from clinker produced.
2. Reduction of radiation of heat to a minimum.
3. Reduction of surplus air over that used in combustion to a minimum.
4. Reduction of temperature of escaping gas to a minimum.
5. Development of the efficiency of the melting chamber to a maximum.

He further recommends an induced draft to control the rate of combustion and the removal and cooling of the gases engendered in burning.

There is no doubt that this could be done and also that the hot clinker could help to heat the air entering the rotary. The idea also of using the super heated air and gases to generate steam to furnish motive power, and packing or lining the surface of the rotary to prevent undue radiation of heat is promising, but their application must hinge on the ingenuity of inventors.

There is no doubt that in many parts of the State the waste heat could be used to aid in evaporating the brine of salt wells so that salt could be produced in connection with cement.

The two weak features of wet marl as a raw material come out in the portion of the process employing the rotaries. High organic matter is said to "clog" the rotaries and if not that, it must be dried and then oxidized so that there is another expense added to the extra cost of conveying it and handling it as slurry. The increased amount of fuel necessary to accomplish this and to drive off the moisture of about 50% in the form of steam is one thing that makes the process expensive as compared with handling dry and compact limestone. It is of course counterbalanced by the extra cost of grinding limestone because the marl is already finely divided by nature.

ESTIMATES OF COST.*

A. 2,400 barrels per day.

Coal Grinding.

4 feeders at \$1.50.....	\$6 00	
2 firemen at \$1.50.....	3 00	
2 general men at \$1.40.....	2 80	
8 tons coal at \$1.50.....	12 00	
		<hr/>
Oil and grease.....		\$25 80
		<hr/>

Burning Department.

2 electricians at \$2.00.....	\$4 00	
2 headburners at \$3.33.....	6 66	
24 underburners at \$1.80.....	43 20	
100 tons slack at \$1.60.....	256 00	
2 oilers at \$2.00.....	4 00	
8 general men at \$1.30.....	4 50	\$328 76
		<hr/>
		\$354 56
10% repair account		35 45
		<hr/>
		\$390 01
		<hr/>

B. 1,200 barrels per day.

Coal Grinding (one shift).

2 feeders at \$1.50.....	\$3 00	
2 firemen at \$1.50.....	3 00	
2 general men at \$1.40.....	2 80	
4 tons of coal at \$1.50.....	6 00	
		<hr/>
Total		\$16 30
		<hr/>
4 feeders at \$1.50.....	\$6 00	
2 firemen at \$1.50.....	3 00	
2 general men at \$1.40.....	2 80	
8 tons coal at \$1.50.....	12 00	
Oil and grease.....	2 00	
		<hr/>
		\$25 40
		<hr/>

*For some of these detailed estimates Mr. Hale is indebted to Mr. Cederberg.

Burning.

2 electricians at \$1.75.....	\$3 50	
2 headburners at \$3.00.....	6 00	
12 underburners at \$1.80.....	21 60	
80 tons slack coal at \$1.60.....	*128 00	
2 oilers at \$1.50.....	3 00	
2 general men at \$1.50.....	3 00	\$171 14
		<hr/>
		\$206 14
10% repair account.....		18 74
		<hr/>
Grand total		206 14
		<hr/>
Cost per barrel.....	17.2	

The cost of burning is estimated by different factories as from 3 to 25 c per barrel, the lowest being that of Hecla cement company, which contemplates mining its own coal on the site of the factory.

One great virtue in the rotary kiln is that by careful watching the control of fuel being perfect the amount of over or under burned cement may be reduced to a minimum. For a view of the clinker end of rotaries with arrangement of coal feeders, see Plate VIII.

§ 14. Clinker grinding.

When the clinker drops from the rotary it must be cooled for grinding. It may be allowed to lie until cool or the process may be hastened. A blast of cool air may be passed over it and this air used as a hot blast in feeding coal into the kiln. For elevation of the whole process see Plate IX (Lathbury and Spackman's Plate I.)

The clinker is gathered in nodules the size of a pea to the size of the fist. When broken across, a nodule shows a steel-like lustre, said to be due to crystals of some soluble silicate. If it is a dead black it is overburned, if of a light gray it is underburned, in either case being worthless. A new scheme of cooling the cement is devised by the Atlas company, which it is said aids in "curing" the cement. It is first passed over hollow rollers through which

*The Omega and Alpena factories use coal dust as will the Hecla.

cool air is passed. This air goes to the rotaries warmed, to feed the coal blast passing into the rotary. The clinker then falls on crushing rollers which break up the larger lumps. These rollers are housed, and fed with a spray of water which dampens the cement and is said to satisfy the calcium oxide not taken up by the silica and alumina and so hasten at once the curing of the cement.*

The whole philosophy of the grinding process is to get a cement ground as finely as possible so that the cementing surface, which will increase with the smallness of the individual particles, will be as great as possible. For this reason the finer the flour to which the cement is reduced the more efficient the brand. The great end of manufacturers is, therefore, to obtain a cement which will be ground finely enough to pass all requirements.

For tests, see table on pp. 681 and 682 of Prof. I. C. Russell's article in the Twenty-second Annual Report of the U. S. Geological Survey, Part III and at the end of Mr. Humphrey's report.

The three different classes of machinery used for cement grinding may be described as millstone, tube mill, and rim roller.

The power consumed by the machinery of the process as reduced to the production of one ton of cement per hour is approximated by Henry Faija, as follows:

	Per ton per hour.
For millstones.....	30 to 32 I. H. P.
Ball principle.....	16 to 18 I. H. P.
Edge runner.....	12 to 14 I. H. P.

Millstones are expensive from the fact that they must be re-dressed so often as to render the process too costly. They are also the most expensive of horse power.

Plates X and XI are illustrations of the Griffin mill, which seems to be the most popular type of the rim roller class.

Plate X shows a battery of Griffin mill at the Alpha Portland Cement Works, Phillipsburgh, N. J. Notice that they are mounted upon concrete foundations and as closely together as possible, for an economical application of power.

Plate XI shows a 30-inch Griffin mill arranged for dry pulverizing. This shows the interior and it is shown how the material is fed down between the roll and its ring or die. These mills deliver a finely ground and crushed grain and are used in over fifty mills in the United States.

*For detailed description see Engineering News, October 24, 1901.

The Griffin mill is undoubtedly one of the best of its class, but does not seem to have been adopted very generally in Michigan.*

Probably the best illustration of the ball principle as manufactured in this country is that represented by F. L. Smidth & Company, 66 Maiden Lane, New York, as given in Plate XII.

This principle, as far as can be learned, is adopted in most of the factories of Michigan and is well adapted to both wet and dry material. It is rather economical of power and turns out a very fine product. Greenland chert pebbles of a very peculiar appearance are used. They are smooth, rather flat, generally ovate or elliptical in shape and have a small groove or indentation in one of their flat surfaces. They are said to withstand the wear of grinding better than anything yet found and are rather widely used for this purpose. The element of cost in this class of grinding is in replacing the pebbles which wear out and contribute to the siliceous content of the ground cement. It is claimed for this class of machine that it does its work quicker than, and turns out as fine a product with as little wear and tear and expense of power as any class of grinding machinery. It would appear that the wear on the machinery would be less than for any other class. For estimate of percentage of cost of grinding for this class of machinery, see the itemized expense of grinding clinker by this process at the close of this section.

The finer the cement is ground the more rough material it is supposed to cement together, as of course, the finer a given piece is the greater surface it will present to cement other materials together. It thus follows that the finer a cement is ground the more it can be adulterated with coarse materials, such as sand. This fact has been taken advantage of in the manufacture of what is called "silica cement." Sand is ground very finely, and mixed with Portland cement, thus going much further than the neat cement, when mixed with coarse sand. For more details see *Cement and Engineering News*, February, 1899.

It will be of interest to mention here some experiments conducted under Prof. A. P. Hood at the Michigan College of Mines, in regard to fineness of grinding. The following are the statement of the purpose and the final results obtained by the experimenters.

1. Test A. Effect of fineness of grinding on tensile strength

*The illustrations were given us by the Bradley Pulverizer Company, 92 State street, Boston, Mass.

of briquette. The experimenter concludes that it makes little difference whether the cement is finely or coarsely ground. The finer and coarser ground being weaker as compared with the medium. This he continues is directly contrary to practice and to all current literature on the subject, and thinks perhaps if the briquettes had been molded better the results would have been different.

B. Effect of different percentages of water used in mixing Wolverine cement. Results. At seven days 15 per cent water* gives highest tensile strength. At 28 days, 20 per cent water gives highest strength.

C. Influence of different grades of sand on tensile strength. Normal sand shows highest strength. With increase of coarseness strength decreases. Standard crushed quartz shows about the average between coarse and normal sand.

D. Effect of different amounts of working of mortar. Working fourteen minutes gives highest tensile strength with a gradual decrease with eight and two minutes working.

E. The comparative strength of four cements were in the following order: Wolverine, Lagendorfer, Bronson and Milwaukee.

The strengths of the cements increase with age, the difference between the seven day test and the twenty-eight day test showing an increase of twenty-five per cent.

Cement mortars, one part cement and one sand, the order of strength is W, B, L, M.

With one part cement and two parts sand, the order of strength is the same as above stated, and the increase of strength from the seven to the twenty-eight day test is about fifteen per cent as compared with the neat.

With one part cement and three parts sand, B has but slight advantage over W, while L and M in order are much weaker, the last named being weakest. Average increase of strength with age not appreciable at twenty-eight days.

In general, Wolverine has greatest strength for all purposes, especially when hardened under water. Bronson has next strength and is very quick setting and can be used to advantage in a damp place. It makes a strong mortar. L comes next and Milwaukee,

*See remarks after Fall's paper, printed in the Mich. Engineer, and at the end of this report.

a natural cement, has a disintegrating tendency under water with but a slight increase in strength.

F, G. Test for compressive strength of the above brands.

Neat cements with compressive strength decrease in the order, W, B, L, M. Mortars: three sand, one cement, decrease in order, B, W, L, M. This test nearly checks that of tensile strength which showed B as best used in mortar. From this the experimenter concludes that tensile strength checks very well with compressive strength, so that the latter tests need not always be made.

These experiments are very interesting indeed, and are a good illustration of one very marked need in the cement business. There is imperative need of tests* along two lines: (1) To determine exactly the best methods to be used in making tests; (2) to find just what is responsible for imperfections in our cements, so that when a cement is tested in the laboratory and found to be good, that it will be sure to prove good when used in a building.

Test A of the above tests, differs radically in its conclusions from the present day practice. We would suggest a test here to supplement that, which will perhaps throw some light upon the reason why the finely ground cement did not prove as useful in giving high tensile strength. If the finer particles are fractured in grinding to a dust, rather than worn down to smoothness, the fractured material should give a higher strength. This idea arises from reasoning by analogy and therefore may be wrong. In a mixture of cement with coarser material, the best results are generally obtained with crushed rock, not rounded pebbles. In testing cement mortars, a crushed quartz gives the highest results for tensile strength. It would seem that there is room for experiment right here to determine if different methods of grinding produce different shaped cement particles with a resulting variation in the tensile strength.

The cost of clinker grinding is estimated by four factories at from 7c to 12c. The grinding and the rotary departments are the ones which experience the most wear and tear and hence should have the greatest expense account. The following is a detailed statement of clinker grinding as estimated at Lupton:

*Compare those reported by Prof. Russell in the 21st Annual Report of the U. S. Geol. Survey, pp. 679 to 682, and the report by R. L. Humphrey.

ESTIMATE OF COST.

Clinker grinding department (Two shifts), 1,200 barrels.

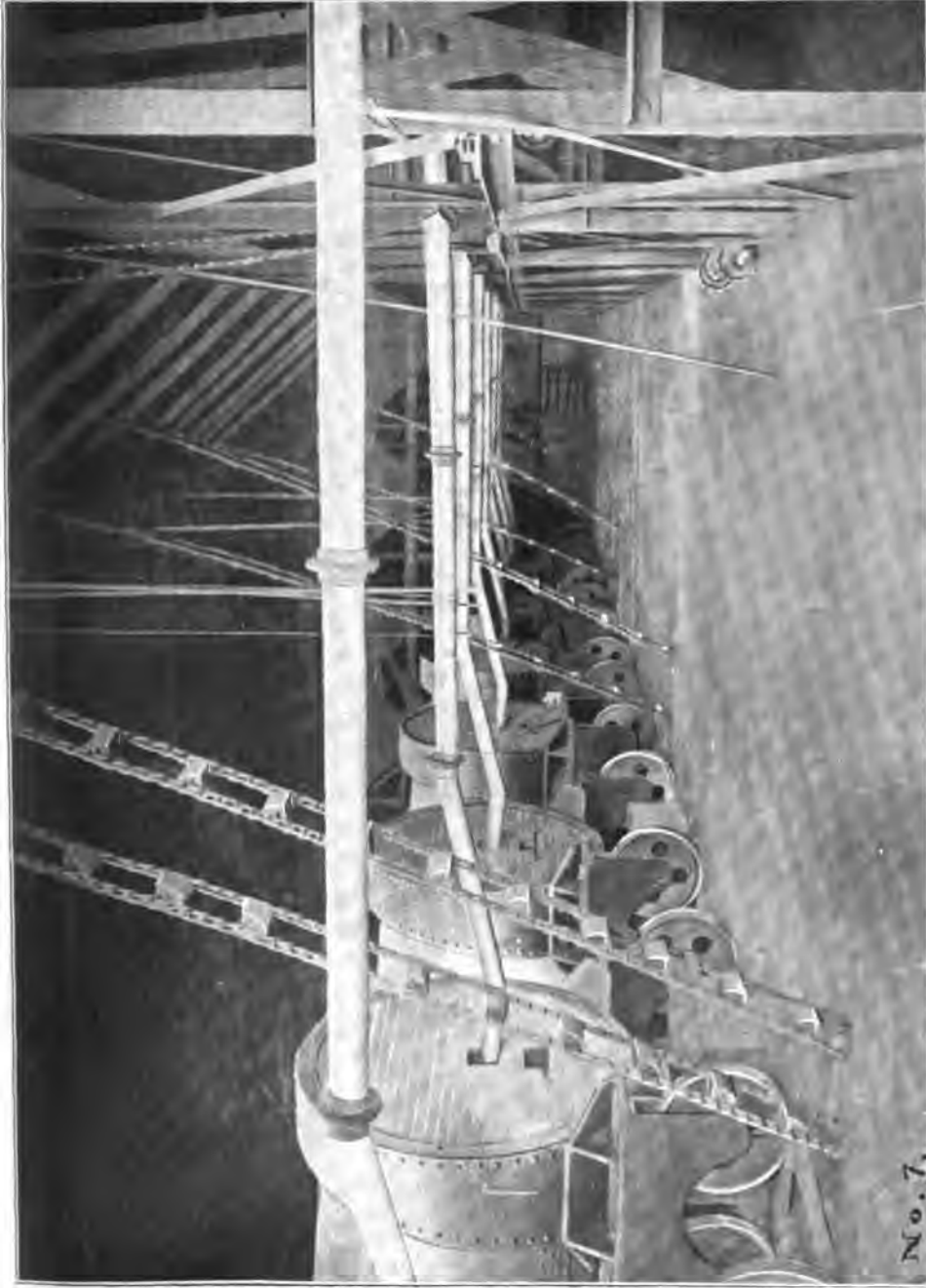
2 electricians at \$2.00.....	\$4 00
2 grinding bosses at \$2.00.....	4 00
4 millers at \$1.75.....	7 00
12 feeders at \$1.50.....	18 00
6 tons plaster at \$10.00.....	60 00
Oil and grease.....	3 00
Total	<u>\$96 00</u>
10% repair account	9 60
Grand total.....	<u><u>\$105 60</u></u>

	Cost per barrel.
2,400 barrels	8.8c
2 electricians at \$2.00.....	\$4 00
2 grinding bosses at \$2.00.....	4 00
4 millers at \$1.75.....	7 00
24 feeders at \$1.50.....	36 00
10 tons plaster at \$10.00.....	100 00
Oil and grease.....	4 00
Total	<u>\$155 00</u>
20% repair account.....	31 00
Grand total.....	<u><u>\$186 00</u></u>
Total	7.8c

Notice large cost of plaster per day. A company might manufacture its own plaster if located favorably for quarrying the raw material. For location of clinker grinders in general plan, see Plates V and IX. For interior view of coarse and fine grinding department, see Plate XIII.

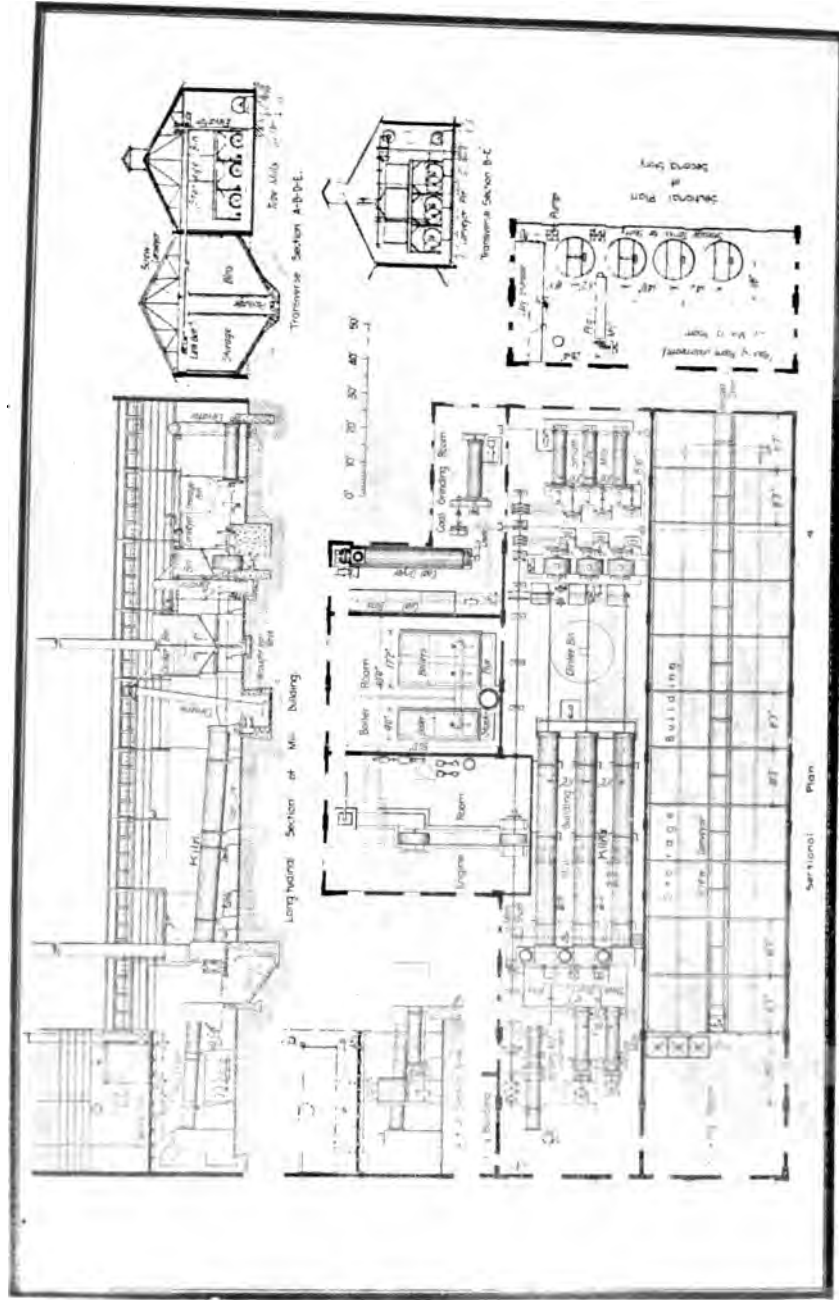
§ 15. Motive power.

This is an important part. The motive power required is great and must be steady, as any breaking down of the main engines stops the whole plant, checks the grinding and cools the rotaries. To be perfectly sure that this will not occur sometimes, as at the Atlas plant, a second engine is fully prepared, so that at any time it may be hitched to the rotaries and cooling apparatus, and the vital part of the process thereby will continue. The storage tanks of slurry are sometimes made large enough to hold a supply of slurry for running the kilns forty-eight hours, so that all but the



FRONT ENDS OF ROTARY KILNS AND CLINKER ELEVATORS

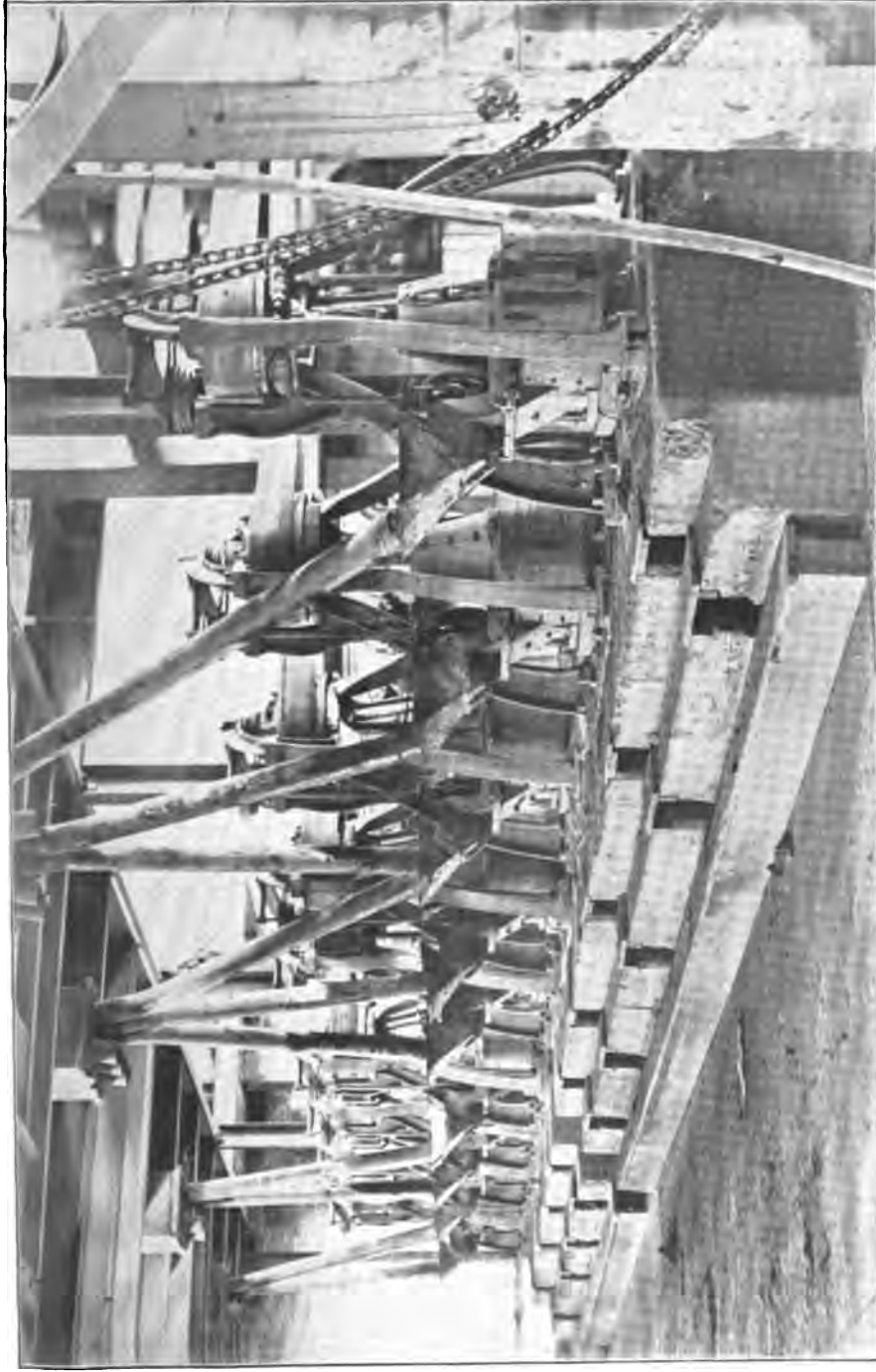
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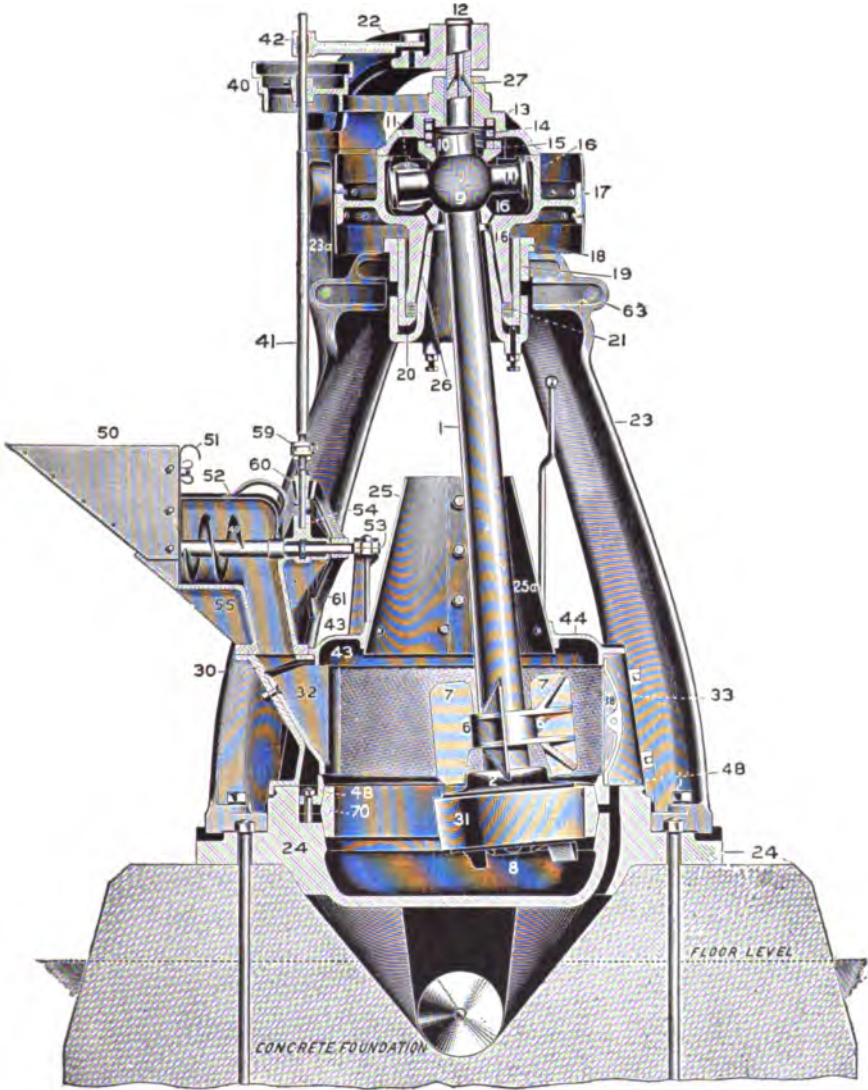
No. 1.

Lathbury & Spackman, Philadelphia, Pa., Engineers.

GENERAL PLAN OF A THREE KILN PLANT WITH ELEVATIONS



BATTERY OF GRIFFIN MILLS GRINDING CLINKER.



CROSS SECTION OF GRIFFIN MILL.

rotaries may be stopped Sunday. There are several new and interesting features to be embodied in the factories of this State relative to power and fuel. The Hecla Cement Company propose to mine their own coal near the site of the factory, thereby reducing their power estimate to 1.28c per barrel, and their burning to 3.25c per barrel. This of course, is the lowest figure given on either step of the process. Another admirable feature would be the use of water power to drive the machinery of the process. This is accomplished by the Newaygo plant. A plan now generally adopted is to transmit the power to the various parts of the process by electricity, making each portion more independent of the others and saving a large waste of power in the transmission.

ESTIMATED COST OF POWER.

The itemized statement of power for the Lupton 1,200 barrels per day, was as follows:

A.

Boiler room:

4 firemen at \$1.60.....	\$6 40	
50 tons of coal at \$1.50.....	75 00	
		<u>\$81 40</u>

B.

Engine room:

2 chief engineers at \$2.75.....	\$5 50	
2 assistant engineers at \$2.00...	4 00	
2 switchboard men at \$2.00....	4 00	
2 wipers at \$1.50.....	3 00	
Oil, etc.....	3 00	
		<u>\$19 50</u>

Total	100 90
10% repair account.....	10 09

Grand total.....	<u>\$110 99</u>
------------------	-----------------

Cost per barrel.....	9.3c
For 2,400 barrel plant it would be	8.2c

§ 16. Storage and packing.

Generally a large space should be given for the storage of cement as it is much improved by "curing." If there is any free lime not taken up and the cement is used at once in building, the satisfied compounds set, leaving the unused calcium oxide to absorb carbon dioxide and to swell, causing the cement to crack. The purpose

of storage bins is to give the calcium oxide time to absorb before the setting takes place, and it also furnishes a supply for large orders, or allows the plant to run when orders are slack and do not call for rush work. The Lathbury and Spackman plans for a seven rotary plant show a storage capacity of 150,000 barrels of cement. So saying that such a plant produces on an average 500 barrels a day, this would allow it to run 300 days without orders, to fill the bins. It pays to have large storage bins as, especially in our State, the factories shut down often from one cause or another, or perhaps to make extensive changes or to enlarge the plant. This large storage prevents the cement leaving the market. It must also be remembered that the demand for cement is greatest only at certain times of the year, and the safest place to store cement is right at the factory, for nothing is so dangerous to its quality as a leaky or damp warehouse. For ground plan and cross-section of warehouse, see Plates V and IX. The interior section of storage bins under construction is also given in Plate IX. This shows the shape of the floor, which is something like an inverted A, so that the bin helps to discharge itself by the force of gravity.

COST OF PACKING.

This is not itemized by most factories, but by the Lupton Cement Company prospectus is carefully shown as follows, for 1,200 barrel plant:

Regular contract rate.....	2.55c
For 2,400 barrels same rate.	
In addition,	
1 foreman	\$2 00
Paper, nails, liners, labels, paste, making	
average cost	3.5c

§ 17. Specifications for cement.

The standard specifications for cement for the Navy Department are as follows:

The cement to be of the best quality of Portland cement, freshly ground, and delivered in canvas sacks, each sack to contain not less than 95 pounds of cement. The sacks to be carefully secured to prevent waste or loss in handling. Sacks to be returned to the contractor from time to time as they are emptied for use in the work. The cement to be delivered at the navy yard in lots of 400 bags each on or before the expiration of ten days notice in writing to deliver each lot. The first delivery to be made within ten days after the date of the contract.

Cement of which a constituent part is derived or manufactured from "slag," or which has not been used in the manufacture of concrete in heavy foundation work for more than three years prior to the time of awarding of this contract, will not be acceptable.

Bidders will be required to submit with their bids certified statements that no "slag" has been or will be used in the cement to be delivered under this contract; also a certified statement of the engineer or architect of buildings or structures wherein this cement has been used in the manufacture of concrete in heavy foundation work, and has proven satisfactory in every respect for the period of three years prior to awarding of this contract. Failure to produce either of the above mentioned certified statements will be sufficient cause to reject the cement delivered by the contractors, without further test, and all rejected cement will be immediately removed from the yard by the contractor and replaced with other cement to fully meet these and all other specified requirements and tests, without cost to the government.

A certified chemical analysis of the cement to be delivered under this contract must be supplied by the contractor prior to the first delivery of said cement.

All cement as delivered will be immediately subjected to the following tests by the civil engineer in charge of the work; failure of the cement to fully meet each and all of the hereinafter described tests will cause rejection of the cement, which must be immediately removed by the contractor and replaced by other cement of a quality to meet the requirements and tests, without cost to the government:

Specific gravity and fineness—Portland cement shall have a specific gravity of not less than 3.1, and shall leave, by weight, a residue of not more than one per cent on a No. 50 sieve, 10 per cent on a No. 100 sieve and 30 per cent on a No. 200 sieve. The sieves being of brass wire cloth, having approximately 2,400, 10,200 and 35,700 meshes per square inch; the diameter of the wire being 0.0090 inches, 0.0045 inches and 0.0020 inches, respectively.

Constancy of volume—Pats of neat cement, three inches in diameter, one-half inch thick, with thin edges, immersed in water after "hard" set, shall show no signs of "checking" or disintegration.

Time of setting—It shall require at least 30 minutes to develop "initial" set; this being determined by means of needles from

pastes of neat cement of normal consistency, the temperature being between 60 degrees and 70 degrees Fahrenheit.

Tensile strength—Briquettes of cement one inch square in cross-section, shall develop the following ultimate tensile strengths:

Twenty-four hours (in water after "hard" set), 150 pounds.

Seven days (one day in air, six days in water), 450 pounds.

Twenty-eight days (one day in air, twenty-seven days in water), 550 pounds.

Seven days (one day in air, six days in water) one part of cement to three parts of standard quartz sand, 170 pounds.

Twenty-eight days (one day in air, twenty-seven days in water) one part of cement to three parts of standard quartz sand, 240 pounds.

The cement depends for its quality upon the amount of soluble silica and the right proportion of lime to supply the same, alumina being also in correct proportion. The finished cement must always be within a very few per cent of a certain standard, the variation being slight. For detailed statement of same and tests applied, see R. L. Humphreys' report on cement testing*. The curing and setting properties of cement are hastened by the addition of gypsum, which counterbalances the effects of over liming. This should not be carried too far, as the sulphates are more or less soluble. It is perhaps owing to the manipulation of tests that many have begun to manifest a distrust of cement tests in general. If the tests as a whole are not conclusive as to the merits of the cement tested, they can not be relied upon, and measures should be taken to remodel the tests, if they are at fault. Averages like the following, if fairly representative, should certainly inspire the greatest confidence in our finished product.

Average of four Michigan factories: seven days, neat 710 pounds, three parts sand 235 pounds; twenty-eight days, neat 824, three parts sand 358.

To compare with this we have the new standard specifications for the navy given above.

§ 18. Buildings.

They should be as nearly as possible fire proof and built of brick, cement or steel. The notices of loss of cement mills by fire are

*For discussion of Hydraulic modulus and cement mixtures see *Cement & Eng. News*, Aug., Sept., 1900; June, 1901. Also pamphlet from their press by S. B. Newberry.

very frequent, and it is not alone the loss of the mill, which may be partly covered by insurance, but the loss of time and the cost of delay in rebuilding to those who have money invested and should have it earning interest on the investment. Furthermore, the cement runs out of the market and much time is lost in getting new contracts and building up the trade again. On this account, the mills that are now building, are using fire proof material as much as possible. At Lupton, corrugated steel buildings, with a supporting wall of six or seven feet of brick, are recommended. In Newaygo, cement was to be used largely. For views of plants and detailed ground plan of same, see Plates III, V and IX.

As near as can be ascertained, to October 4, 1901, the following is the condition of the cement industry in Michigan:

Eight factories are running a total of 48 rotaries, which is an average of six rotaries per factory.

Nine factories, three in addition to those mentioned, intend to put into operation 132 rotaries. There are seven other factories silent upon the subject of output, which are incorporated under the laws of the State. There are 25 factories in the State which have issued prospectuses or become incorporated, either under the laws of this or other states.

Of 20 factories whose capitalization could be ascertained from prospectuses or other sources, the lowest capitalization was \$20,000, the highest \$5,000,000. The average was \$1,004,500.

For statistics showing the condition of cement mills and market at any given time, consult the reports of the Michigan Commissioner of Labor.

The proposed cost of the Newaygo plant is to be about \$500,000, the buildings are to cover five acres, and to hold at least 14 rotaries. The Standard Portland cement plant will be equipped with an outfit costing \$350,000, and with a working capacity of 1,000 barrels per day. F. L. Smidth & Co., 66 Maiden Lane, New York, estimate the cost of buildings and apparatus for a 500 barrel plant at \$125,000 to \$150,000, depending somewhat upon location. This seems much lower than the equipment of the plants which are actually building. The Elk Rapids plant cost about \$200,000.

§ 19. Review.

In review of this chapter a most apparent fact is, that there will be, in the near future, severe and destructive competition in Michigan. The editor of the Cement and Engineering News is authority

for the statement that in the spring of 1901, contracts were closed for Portland cement at 80 cents per barrel, f. o. b. The Michigan factories are in a comparatively limited area and must nearly all compete in the same markets. At the average estimated cost of the cement as given by the various prospectuses (68c), the addition of very high freight rates will destroy the profits and limit the area of markets. With 48 rotaries going and 132 to be running in the near future, the actual output of well established factories will be shortly trebled.

In considering these figures it must be further remembered that a factory just started must generally introduce its brand by offering it at considerable below the market price, to obtain a foothold in the market at once.

A brief enumeration of the points which will win in this competition are as follows:

The purest raw materials.

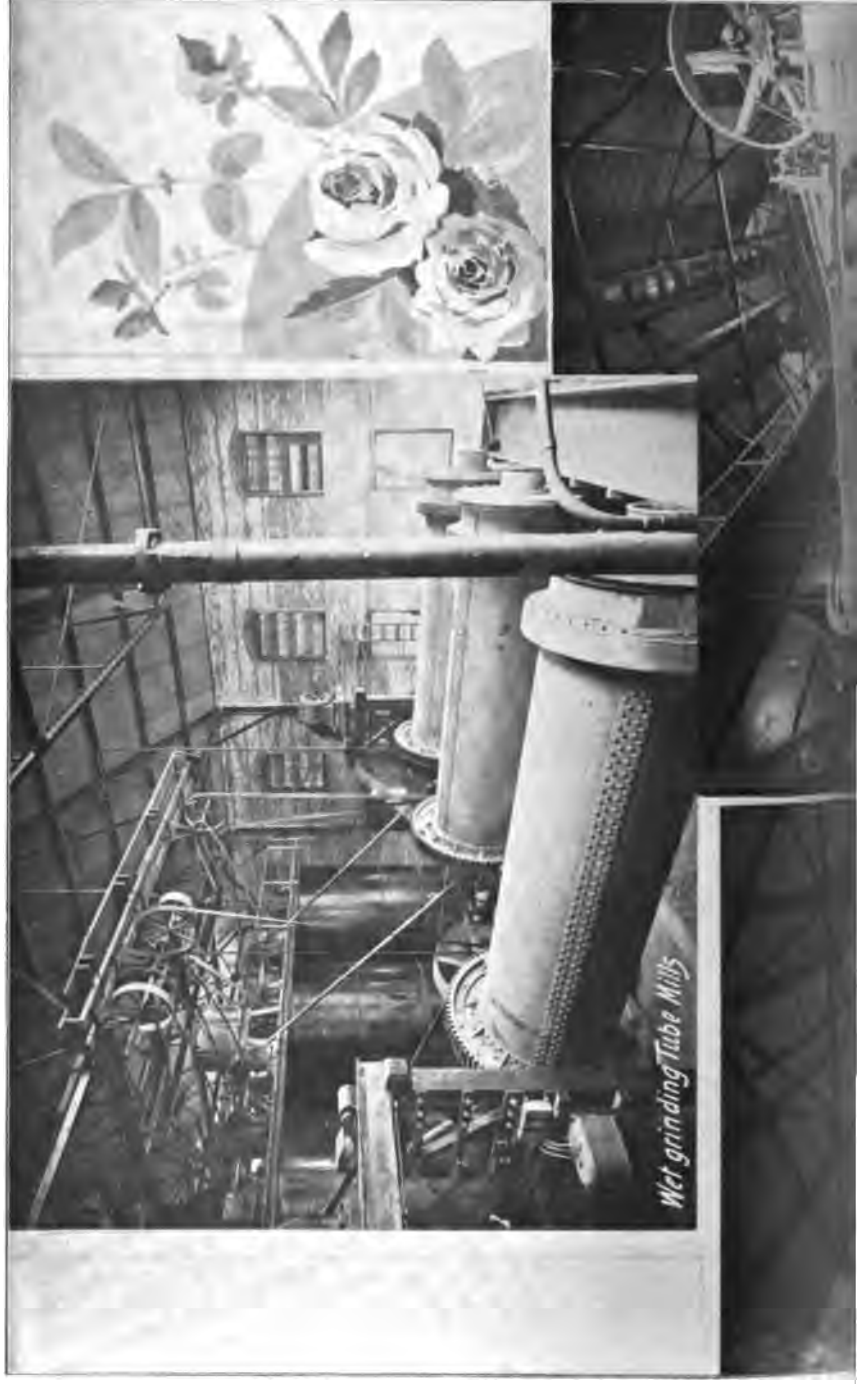
The largest plant with the strongest machinery purchasable. A. H. Cederburg estimated a decreased cost of 10c per barrel upon doubling the output.

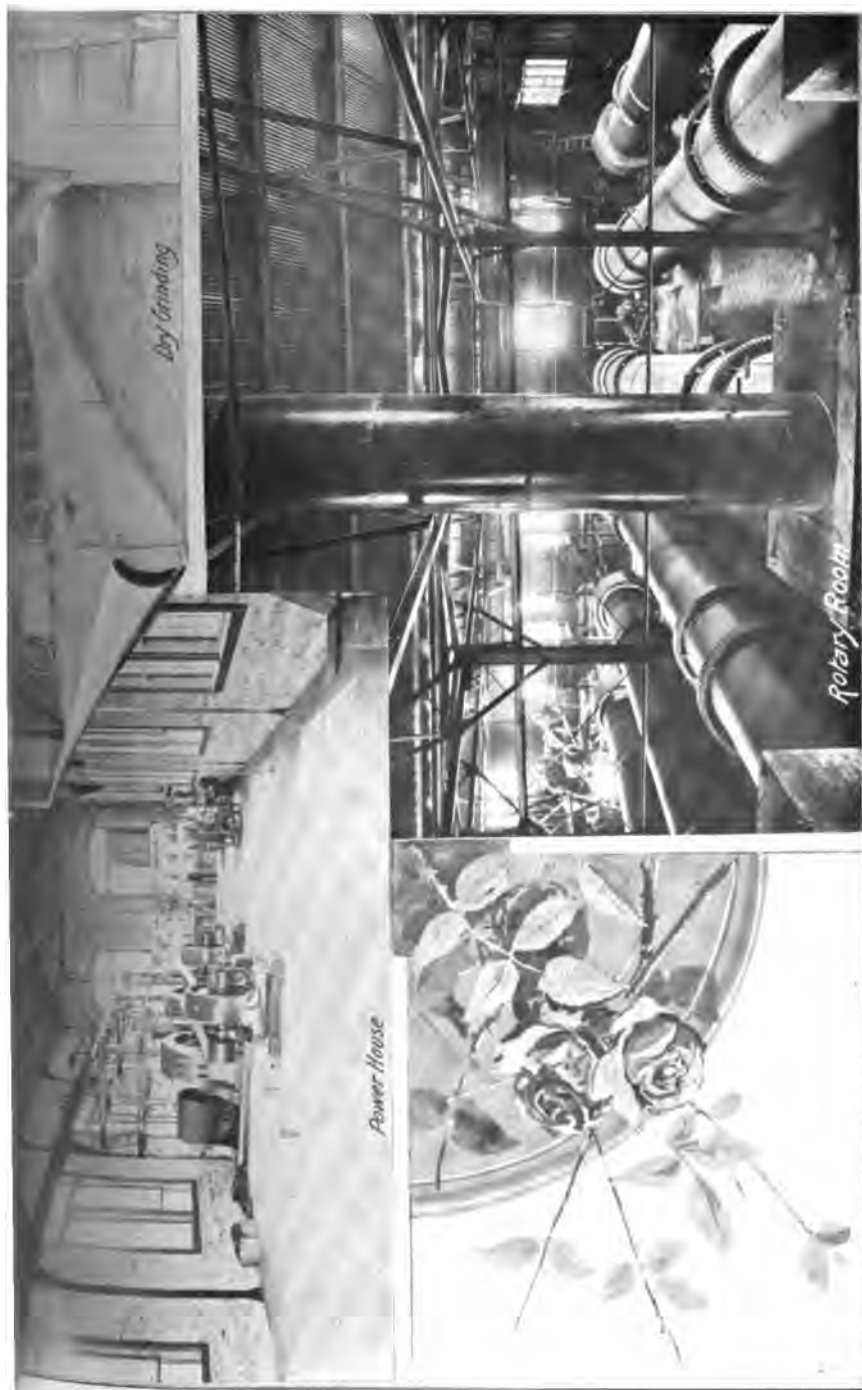
Cheap power, either through available water power, or coal mined on site.

Most suitable location as regards raw material, fuel and market.

The more of the above requisites possessed by any one factory, the higher will be its profits.

*At present (last reading of page proof, Oct. 1902), however the price of cement has risen again and is over \$2.00 a barrel, the low prices mentioned having stimulated a demand for cement in many new directions, with which the supply has not kept up. Especially in constructional work, for bridges and buildings, as well as sidewalks and cellars, a field for the use of cement has opened to which it is at present hard to set limits. L.





VIEWS IN NEWAYGO CEMENT PLANT, BY R. L. HUMPHREY.

APPENDIX TO CHAPTER VIII.

**THE DEVELOPMENT OF MARL AND CLAY PROPERTIES
FOR THE MANUFACTURE OF PORTLAND CEMENT.**

BY B. B. LATHBURY.

The exploitation of a marl or clay deposit involves a large amount of labor, and with it the necessity of an accurate and careful investigation of the quality and quantity of the materials, their general conditions, together with their advantages characteristic of the site from both an engineering and an economic standpoint. During the past few years, which might aptly be termed the construction period of the Portland cement industry in the State of Michigan, the investigation of such deposits have been conducted on purely scientific lines. Briefly described the method of procedure, in order to secure accuracy in the results and reliable figures upon which to base financial calculations for exhibiting the proposition as an attractive investment, is as follows:

The marl deposits should first be carefully surveyed and soundings located at convenient points over the entire deposit, from which samples of the marl should be secured, and the depths ascertained for each sounding. The most suitable time for such an investigation is the winter, when the water over the deposits, if located in a lake bed, is usually frozen. This permits meridian lines being laid out over the entire surface, thus forming squares of known size, at the corners of which holes can be bored in order to ascertain the depths and quality of the material. Field notes are usually kept of such an investigation, and the samples are carefully preserved with the number of the hole from which they are taken. The distance apart of each sounding or bore hole depends in a great measure upon the uniformity of the material and the variation in depth of the deposit, but generally speaking, on a plat laid out in measured squares, the lines of which are located by a transit, bore holes can be made every 300 or 200 feet. The survey should then be accurately platted, a map made showing the boundaries of the deposit, together with the location and depth of all bore holes, their consecutive number on the plat, and if the

deposit is under water, the depth of water over the surface of the marl.

The examination of a marl bed underlying a body of water is much more difficult and less accurate if made when there is no ice covering the surface of the water. Under such conditions, it is generally usual to survey the boundary lines of the lake, establishing stations at measured distances on the banks, and from these points, with the aid of a boat, secure samples and make soundings, in practically the same manner as a hydrographical survey is conducted. The boat is rowed over imaginary lines between the stations on the shore, borings being made and samples taken at intervals over the deposit. If the deposit of marl occurs in a dry state or underlying a swamp, the examination is conducted by laying out meridian lines over an established survey, the borings and samples being taken from the intersection of all lines forming squares.

The next course to pursue is to submit the samples of marl to some competent testing laboratory familiar with the manufacture of cement by whom the samples should be carefully analyzed and determinations made for the following ingredients:

Calcium oxide, silica, combined oxides of iron and alumina, magnesium oxide, sulphuric anhydride, together with the loss on ignition. Determinations can be made for alkalies and other elements, but as they exist in such minute quantities, their determination will not prove of commercial value. The other ingredient to be considered is the clay or shale. Clays throughout the State of Michigan are usually found in a blue color, but when existing in connection with the marls, they usually carry a higher magnesium content than is desirable for the manufacture of Portland cement. On the other hand the suitable shales, though comparatively scarce, are notably free from deleterious elements, and better adapted for Portland cement purposes.

An examination of either the clay or shale deposits should be conducted on the same lines as those pursued for the marl investigation, analyses being made on the samples of clay in order to determine their uniformity and quality. The elements to be determined in the chemical analyses are similar in all respects to those enumerated for marl, with the exceptions of the oxides of iron and alumina should be separated. In all cases after the examination has been made, the data should be collected and a careful

computation made of the quantities of suitable marl and clay occurring in each deposit. Then assuming as a conservative unit, that one square yard of marl will manufacture two and a half barrels of cement, it is readily computed the number of barrels of cement that can be manufactured from the deposit and the number of years a mill of given capacity will run.

In general, a marl of good quality should contain over 50% of calcium oxide, with not over 1½% magnesium oxide, and less than 2½% of either silica, combined iron and alumina oxide, or sulphuric acid. Although there are many marls found in the State of Michigan containing less than 50% calcium oxide having the other ingredients in proper proportions, these low lime marls usually contain a high per cent of organic matter which represents so much loss in the available quantity of marl. However, such marls can be used for the manufacture of a high grade of Portland cement, provided a suitable clay or shale is used in conjunction with them. A clay or shale of good chemical proportion should contain in general, not less than two parts of silica, to one part of combined iron and alumina, while the oxide of magnesia should not be over 3%, and the sulphuric acid less than 2%. The clays throughout Michigan usually contain a small lime content, but this is not detrimental to their use for Portland cement mixture, provided care is exercised in correctly proportioning the two ingredients if the magnesia content is low. As a rule it will be found that clays carrying over 10% of lime will be too high in magnesia.

The quality and quantity of the marl, clay or shale deposits having been found satisfactory and the capacity of the mill been decided upon, the services of competent engineers should be engaged to prepare plans and make a final report on the property, and which report is usually used in connection with the prospectus for promoting the financial interests of the corporation.

A matter of great importance, which should be carefully investigated, before the erection of a plant, is that referring to freight rates. This question applies not only to the advantages derived from securing low rates for the shipment of cement to main distributing centers, but also to the careful consideration and selection of a site for the erection of a plant. Generally speaking, it is more desirable to erect a plant alongside of the marl deposit, but in some cases direct water and rail shipment can be made by erecting the factory some distance from the marl and clay deposit,

provided a low guaranteed rate can be secured, and the haul is not too great, for the transfer of both the marl and clay from the deposits to the mill site. A plant so located possesses many undisputed advantages.

The cost of a modern rotary Portland cement plant varies largely with the character of the buildings and the mechanical equipment. A plant thoroughly up to date in mechanical equipment, using electricity for the transmission of power, and with steel frame buildings having brick sides, can usually be figured at \$50,000 for each rotary kiln completely installed. Each kiln has an average capacity of about 125 barrels per day, but its daily capacity varies with the size of the kiln, skill of the operator, fusibility of the slurry burned, and general conditions of the plant. In general, therefore, it is safe to assume the cost of construction at \$400.00 for each barrel of cement to be produced. This, however, does not allow a working capital, which in round figures should be 20% of the total cost of the plant. It represents, however, the entire cost and equipment of a thoroughly modern and up to date plant manufacturing Portland cement by the wet process, either from marl and clay or marl and shale, including such equipment as is needed for excavating and handling the raw material. The most economical process would necessarily embody such machinery as would eliminate manual labor and reduce the cost of repairs to a minimum. Such an equipment is contemplated in this estimate, and would include disintegrators for the marl and clay, tube mills for grinding, and pumps for handling the slurry, sufficient storage capacity for both the clay and marl ingredients, and also for the slurry mixture of the two previous to being transferred to the kilns. These storage tanks to be equipped with suitable agitators in order that the slurry may be kept in a state of constant motion. Kilns 60 feet long by six feet in diameter to be used, equipped with pulverized coal for burning the slurry. Suitable cooling arrangements should be provided for storing and cooling the hot clinker before it is finally ground into cement; the stockhouse so designed that the bins will automatically discharge the finished cement into conveyors which carry it to the packing room, while the packing room would contain automatic packers for both barrels and bags. The plant would be thoroughly equipped with a heavy and durable elevating and conveying system in order to handle both the raw and finished materials.

Most of the plants heretofore erected have utilized shafting for the transmission of power, but experiments made in one or two mills have demonstrated the adaptability of electrical installation, doing away entirely with troublesome line shafts and cumbersome and unsightly piers upon which the shafting bearings necessarily rest.

Several of the modern plants at present under construction in the State of Michigan are installing electricity for the transmission of power. Such an installation costs about 10% more than the installation of shafting for transmitting power, but it effects a considerable saving in the floor area of the buildings, as shafting transmission of power necessarily requires buildings with larger floor space. In maintenance, the electrical equipment is probably less in cost of a cement plant than the shafting, though no accurate data is yet obtainable upon which to base a comparison.

In the matter of engines and boilers, it is desirable to use compound condensing engines with water tube boilers, and if the capacity of the plant is over 1,000 barrels per day, automatic stokers should be provided. Approximately it requires about one horse power for every barrel of cement capacity.

Electrical installation can be made with either the direct or alternating current. Between these two systems there is very little difference in the first cost of installation. The dynamos and motors for the alternating current are more costly than the same machinery built for the direct current, but the saving in the general system of wiring and connections for the alternating current about offsets the extra cost of the wiring and connections of the direct current system. While both systems are equally adapted for direct connected or belted drives, direct current installations with separate motors driving each machine have been most generally used, although there are now in operation two plants, one using alternating current and the other direct current motors, in which each machine is directly connected without the intervention of belt or shafting to the motor driving it.

Between the two systems of power transmission, that is, shafting and electricity, the latter is probably the more economical, but to offset this, it requires more skilled care and attention. Electricity, however, has one great advantage, in that it offers a more flexible plant, wherein power can better be distributed and economy ob-

served by the operation of any combination of machines, under all conditions.

Aside from the correct proportioning, mixing, and burning of the slurry to a proper degree of hardness, the power plant is a department upon which great care and thought should be exercised. As coal represents such a large item in the cost of production, the power plant installed should be such that the highest economy and efficiency can be obtained.

The cost of construction of a rotary plant can be reduced to \$300.00 for each barrel of the capacity by the use of steel buildings covered with corrugated iron sides and roof, the omission of electrical equipment and the installation of a less costly power plant. The cost of construction can be still further reduced by the construction of frame buildings and the omission of all labor-saving devices throughout the plant which would necessitate the handling of a large part of the raw, unfinished product by manual labor. Such construction would necessarily increase the cost of production of the finished cement and thereby decrease the profits.

The preceding outlines contemplated the use exclusively of rotary kilns, but there is yet an entirely different system which can be installed, and for which the cost of erection would not exceed \$200.00 for each barrel of the capacity. This refers more particularly to the installation of set kilns, together with such machinery for mixing and grinding the marl and clay or marl and shale in a semi-plastic condition, forming same into bricks which are afterwards dried and then burning the raw material in some form of a set kiln. The Dietsch and Schofer kilns, classed as the best of this type, require the expenditure of a large amount of manual labor in order to prepare the raw material, charge the kilns and handle the clinker, after it has been thoroughly burned. Small consideration is given to this method of manufacture in this country at the present time, and it has been almost entirely superseded by the rotary kiln, principally because of the increased production of the rotary kiln over the set kiln, and the opportunities offered with the rotary system of utilizing mechanical devices for handling the raw and finished products, and thus effecting a large saving in the item of labor. Assuming the capacity of a rotary plant at 1,000 barrels per day, it requires about nine months to complete the erection, and about three months thereafter, or one year after

starting erection, before it is in full running order, and turning out its maximum capacity of marketable cement.

With the progress made in the Portland cement industry during the past five years, it is not a profitable venture to install less than three or four kilns on the erection of a new plant, and the plant should be so designed that the buildings can be readily increased and the capacity doubled or tripled without interfering in any way with the operation of the initial plant. The larger profits in the present condition of the cement market are to be derived from large productions.

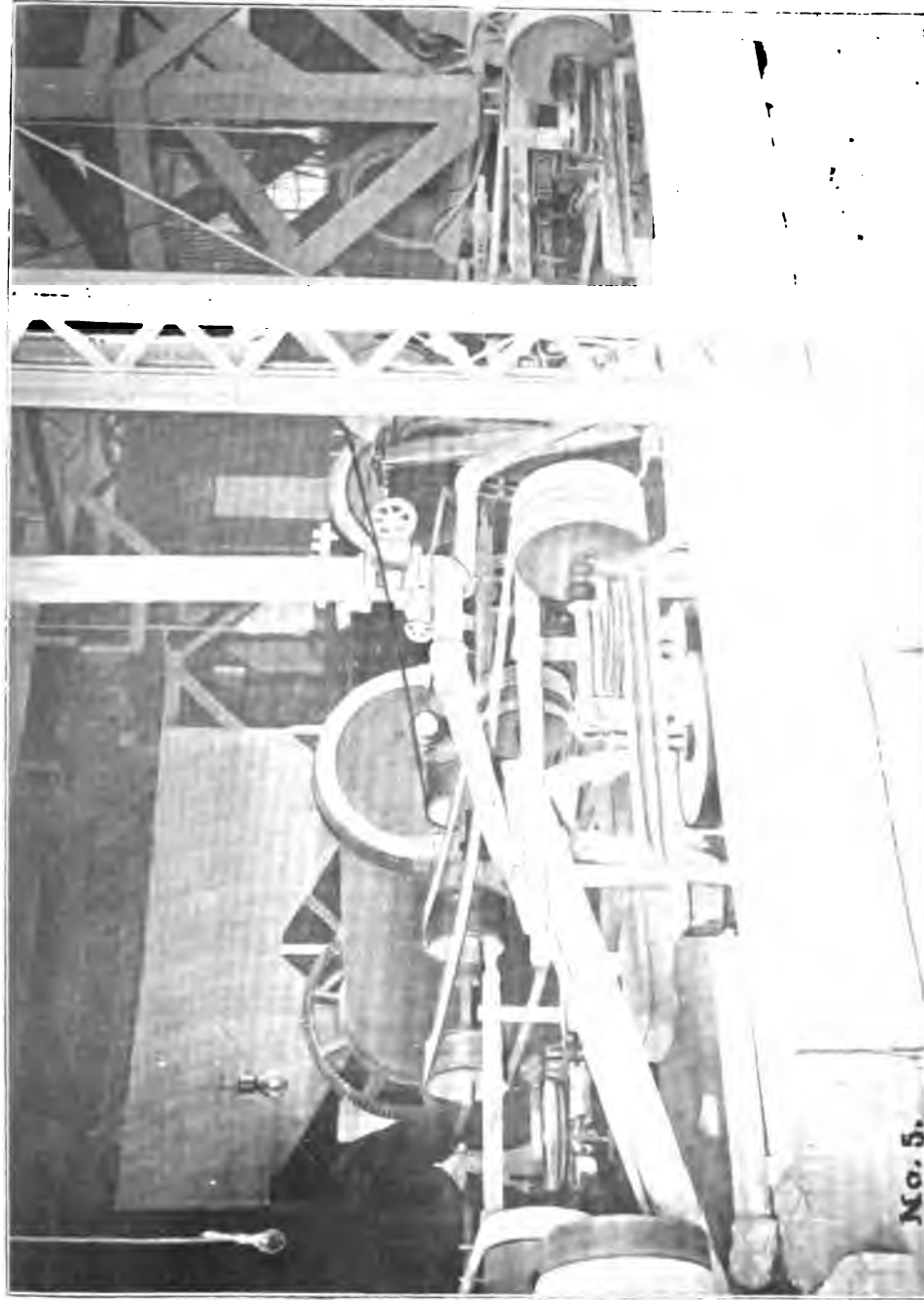
During the construction of the plant it is absolutely important that careful consideration be given to the selection of a competent superintendent, master mechanic, electrician and chief chemist, in order that they may report for duty during the last stages of construction, and thus become familiar with the plant. These heads representing the executive force at the mill, should be men who have a thorough experience and knowledge in the manufacture of Portland cement, operating under similar conditions. Upon the skill of these men depend in a large measure, the prospective profits to be derived from the investment. Many mistakes have heretofore been made by filling these positions at the mill with men who have had no experience in the manufacture of cement. Upon these men, working in harmony with a careful and efficient higher management, depends in a measure the success of the venture. It is generally conceded by all who have had experience in the manufacture of Portland cement that it is one of the most difficult and trying lines of manufacture. This is due to the excessive wear and tear on the machinery, due to the hard and constant use to which it is put, requiring constant watchfulness in order to detect defects and wearing parts, with skill and judgment, in remedying the same before final breakdowns occur, necessitating the shutting down of the entire plant.

The cost of manufacture varies greatly in each plant, ranging from 80 cents to \$1.40 per barrel of cement produced. This variation depends on several reasons, principal among which is the general design and construction of the plant, efficiency of the entire management, daily condition of the machinery, cost of all raw materials delivered at the mill, including marl, clay, and coal, and cost of labor and size of the mill.

A brief summary of the foregoing facts would therefore tend to show that a cement proposition should be carefully handled from the earliest stages of its development, until the plant is finally erected, after which the success or failure of the venture depends in a great measure on the skill and competency of the engineers who have erected the plant and reported on the general conditions favorable to manufacture, together with the general management selected to handle the business of the company.

The views accompanying this article are as follows:

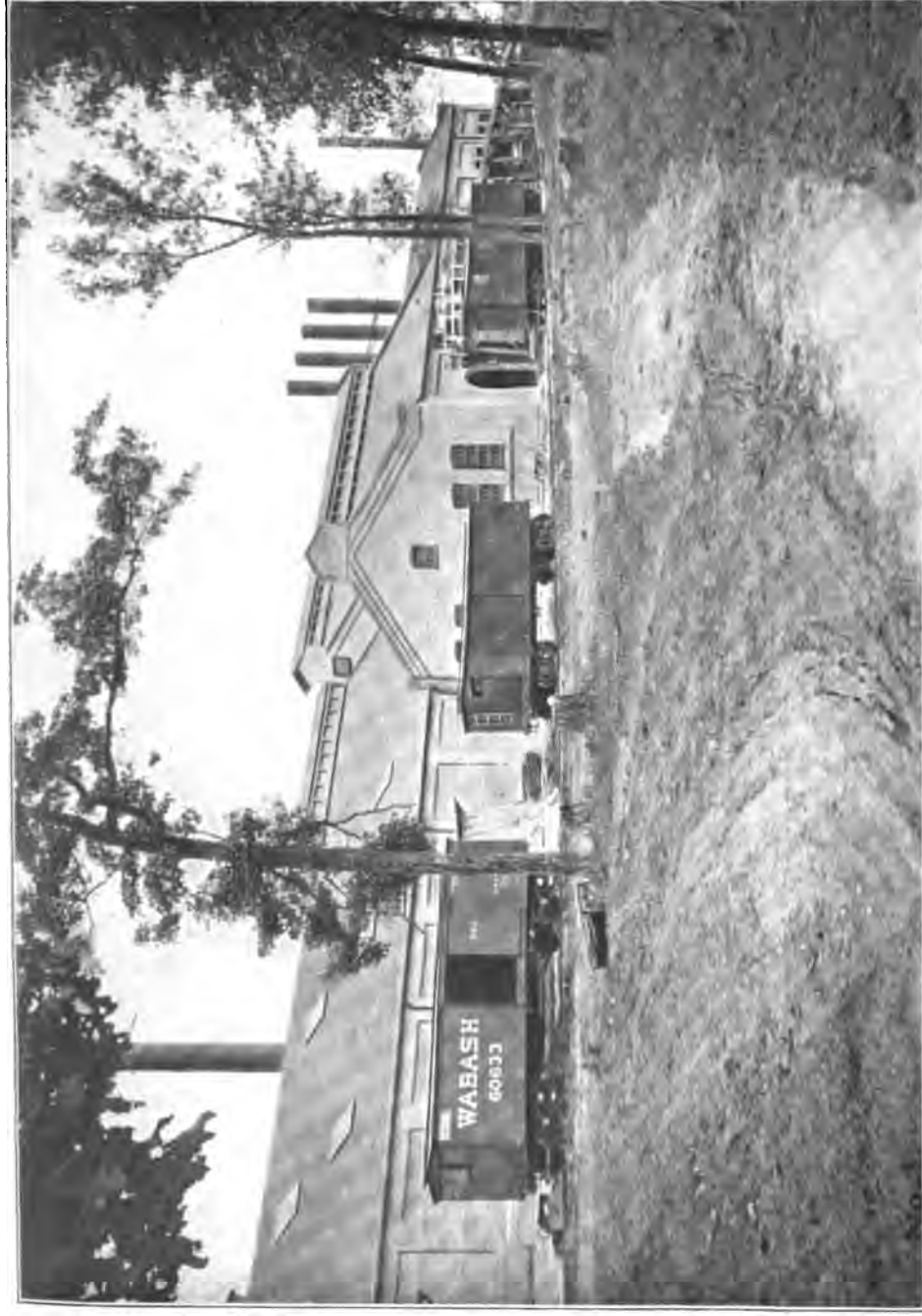
- Plate IV. General exterior view of an eleven-kiln plant.
- Plate V. General plan of a complete plant having an installation of four kilns with sufficient floor space for installing the necessary grinding machinery to bring the capacity up to 1,000 barrels per day, which would only necessitate the extension of the kiln building.
- Plate VI. General interior view, showing a modern slurry department in operation.
- Plate VII. General view showing a modern rotary kiln 60 feet long by 6 feet in diameter.
- Plate VIII. General interior view showing the front hoods of a battery of eight rotary kilns with hot clinker elevators, pulverized coal bins with apparatus and piping for forcing coal into the kilns.
- Plate IX. General plan of a complete plant having an installation of three kilns, without provision for future extension.
- Plate XIII. General interior view showing batteries of ball and tube mills in operation grinding Portland cement clinker.
- Plate XIV. Four views as follows:
- A. A modern office building with chemical and physical laboratories and a few sleeping rooms for superintendent and his assistants.
 - B. View showing section of a stockhouse under construction to have self-discharging bins.
 - C. View showing bottom of concrete slurry pits under construction, with piping and valves being set in position for handling the slurry mixture.
 - D. View showing a dry marl deposit with car and steel rope attached, for hauling the marl from the bed to the slurry department of the mill.
- Plate XV. General exterior of a four-kiln plant.



GENERAL INTERIOR VIEW SHOWING TUBE MILLS



A.—Office building with laboratories, etc.
B.—Stockhouse with self discharging bins under construction.
C.—Bottom of concrete slurry pits under construction.
D.—Dry marl deposit with hauling arrangement.



GENERAL EXTERIOR VIEW OF A FOUR KILN PLANT.

CHAPTER VIII.

NOTES ON THE ORIGIN OF MICHIGAN BOGLIMES.

BY A. C. LANE.

§ 1. Introduction.

It was the original intention to have this report prepared entirely by Mr. Hale, but the subject grew upon him, just as the Portland cement industry has grown in the State. Moreover, work like that which Mr. Davis, and Lathbury and Spackman have done seemed too large to be incorporated without credit to them as authors. Other information also kept coming in which deserved an incorporation, that I could myself, with less delay than any other, perform, and at the same time insert some comments on the theories of the origin of boglimes, presented by the others, that I could not very well insert into their papers.

§ 2. Origin of boglime, chemical considerations.

It must not be forgotten in discussing the origin of these fresh water lime oozes, limestone doughs, so to speak, that it is perfectly possible for more than one method of formation to produce very similar material. It is possible that the Indiana geologists may be right¹ in their conclusions as to the origin of their deposits, and Davis and Hale also right as to the origin of those boglimes they have studied. But the crucial point in discussing any theory of purely chemical precipitation is this: Is there any evidence of such saturation of ground water with calcium bicarbonate, that any loss of temperature and pressure likely to exist will cause precipitation by purely chemical means? Therein lies the importance of the tests made by and for Mr. Hale, given above² and we may also compare, for the hardness of spring water, analyses 52-80 of my paper on the water analyses of this State.³ In these CaCO_3 varies from 0.12 to 0.40 parts per thousand,⁴ yet in only five cases is it

¹Twenty-fifth Annual Report, p. 48.

²PP. 46 and 118.

³U. S. G. S., Water Supply Paper No. 30.

⁴Grams per kilogram, ounces per cubic foot nearly.

over .20 of carbonate or bicarbonate. To these analyses may be added one of the Owosso mineral water which is a natural spring, flowing from the side of the hill about 11 barrels a minute, at a temperature of 50° F.

	Parts per M.
Calcium bicarbonate.....	.367
Magnesium bicarbonate.....	.273
Iron bicarbonate.....	.227
Sodium and potassium chlorides.....	.030
Silica and alumina.....	.009
	<hr/>
	.906

Mr. J. G. Dean of the Peninsula cement plant informs me that the water of Goose Lake, near the mouth of their intake yielded:

CaO .....	.110
MgO .....	.044
(Fe, Al) ₂ O ₃	tr.
SiO ₂ .....	.004
SO ₃ .....	.014
CO ₂ .....	.108
(Na, K) ₂ O .....	.004
	<hr/>
	.284

This implies .262 parts per thousand of calcium and magnesium carbonate, and if this is saturation for average lake conditions, then about one-third of the ground waters above referred to reach it.

Treadwell and Reuter made no researches on the solubilities of calcium and magnesium carbonates together in the same solution, but as they find that calcium carbonate may exist to the extent of only .238 parts per thousand, if no free CO₂ is present, it must be near the point of saturation.

The solubilities of the carbonates are so important and the paper is so comparatively inaccessible here, and besides has a number of misprints, and misplacements of text, which Mr. Treadwell has kindly corrected for me, that I think it worth while to give the following summary in the hope that some of our cement factory chemists may feel impelled to continue an investigation, in which the survey might coöperate.

Abstract of article "Ueber die Löslichkeit der Bicarbonate des Calciums und Magnesiums von F. P. Treadwell and M. Reuter" with 11 figures in the text. *Zeitschrift für Anorganische Chemie*, Vol. 17, p. 170.

It is well known that bicarbonated water gradually becomes cloudy upon exposure to the air, while calcium carbonate separates as a thin crystalline film on the surface of the fluid, and that the separation increases as the absorbed CO_2 escapes. It follows that if calcium bicarbonate was in solution, the solubility of the same stands in relation to the free CO_2 . Data as to the solubility of this

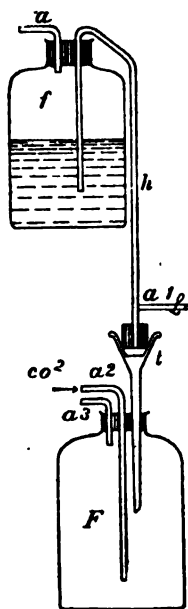


Fig. 16.

salt are rare in literature; indeed, its very existence has been doubted. It was accordingly of interest to investigate the existence and solubility in carbonated and non-carbonated waters of bicarbonates especially of the alkaline earths. Calcium, magnesium, and sodium bicarbonate came within the range of investigation. The method employed for the special case of the calcium salt may be briefly sketched.

Distilled water was saturated with CO_2 and CaO in a closed bottle, the partial pressure of the CO_2 on the fluid being one atmosphere, i. e., the gas above the water was pure CO_2 .

Fig. 16 shows the apparatus used for filtering off the water from the upper bottle f, where the quicklime was to the lower F without allowing access of air and loss of pressure of carbon dioxide.

The solution, filling about the half of a large bottle, remained after filtration but without alteration of the partial pressure, clear for days,* and the *per cent of CaO does not alter in the slightest*, as is evident from the analyses below.

A part of the CO_2 above the water was replaced by air, until separation of carbonates was observable. This is the point at which the most possible CaO can be taken up, for the temperature and pressure then prevailing. By successive lessening of the partial pressure of the CO_2 the calcium was more and more separated, until finally when the partial pressure reduced to 0, no further alteration in the lime took place. The water then contained, as was shown by analyses, *calcium and CO_2 exactly in the ratio to form bicarbonate*. Accordingly an aqueous solution of calcium bicarbonate is present.

The problem was then to determine exactly at each time the partial pressure of the CO_2 resting upon the fluid as well as the per cent of CaO and CO_2 in the solution. To this end the apparatus illustrated by Fig. 17 was used.

The bottles F_1 and F_2 contain two of the solutions to be investigated separately. The gas is drawn out through the tubes r_2 . These are perforated at distances of about 2cm in their vertical parts (so as to get a fair sample of air), and outside of the neck of the bottle are bent at right angles. The horizontal parts have glass stopcocks, h_1 and h_3 , and T pieces, t_1 and t_2 , and n_1 and n_3 are pressure level tubes, which can also be closed by stopcocks. Mercury is the fluid that fills them. In their prolongation the tubes open into the common capillary C, which has a small funnel, n_2 , above, and below is closed by a thick walled rubber pipe and clamp. The arrangement is to avoid as far as may be, the injurious space between the cocks h_1 and h_3 and the opening of the capillary pipette. If the cocks h_1 , h_3 and s are closed and the other cocks open, by raising the level tubes n_1 and n_3 , all of the air will be

*The experiments were performed at a constant temperature and pressure. The mean temperature of 15 degrees Celsius was chosen (59° F.), which it was possible to keep exactly only by placing the apparatus in a room which was not subject to great variations (amounting to 1 to 2 tenths of a degree during the whole investigation).

The slight differences in the temperature could be neglected but the variations in pressure were considerable, so that all the data had to be reduced to the normal conditions of 0 degrees and 760 mm. of mercury pressure.

forced out of the tube system and the same will be gradually filled with mercury. When this has risen to the desired height in n_2 , q_4 , h_2 and h_4 are closed, and the thick tube at s is fitted over the pipette filled completely with mercury. The suction is applied at O (by a Sprengel pump) while the cocks s and h (or h_3) is opened until the globe of the pipette is full and then s is closed. It is advisable to repeat this operation two or three times. After the last time, first h_1 or h_3 is shut and the capillary of the pipette is filled with mercury by opening the clamp of q_4 a moment. The gas is now

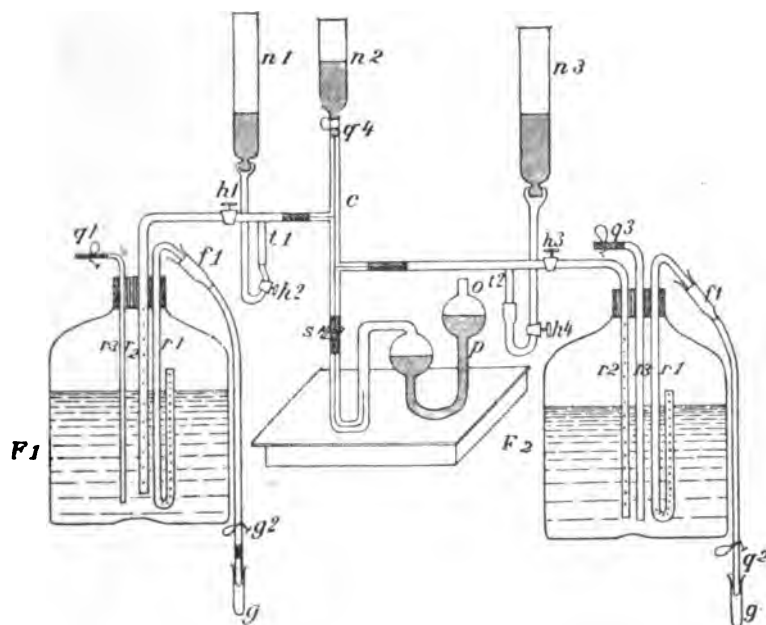


Fig. 17.

ready for analysis, which was done by Hempel's Exacter method. (Gas analytische methode, p. 45.)

The analysis of the solution falls into two parts.

- a. Determination of the total CO_2 .
- b. Determination of CaO and combined CO_2 .

Here also it is important to obtain an average sample, for it is clear that the water does not give off its absorbed CO_2 equally in each horizontal stratum. The upper layers lose the most, the lower the least gas. Referring again to Fig. 17, the tube x goes through a perforation in the rubber cork. It is bent inside the tube and

perforated in the ascending part at distances of 1cm. It works like a syphon. Any carbonate crystals possibly taken with the fluid are held back in the little filters at *f*. These are short glass tubes, somewhat expanded at the end, the cone of which is best packed with asbestos. Upon this goes a rubber tube, which ends in a short glass tube, over which, to prevent evaporation, a short test tube is tightly fitted. By light pressing on the clamp, *q*₂, any amount of water desired can be taken.

The small flask *A** (Fig. 18) is exactly gaged by weighing with water filled up to a certain mark, and can be closed by a rubber cork through which goes a λ shaped glass tube (*R*) which has a side opening a little above the end of one of the forks which is

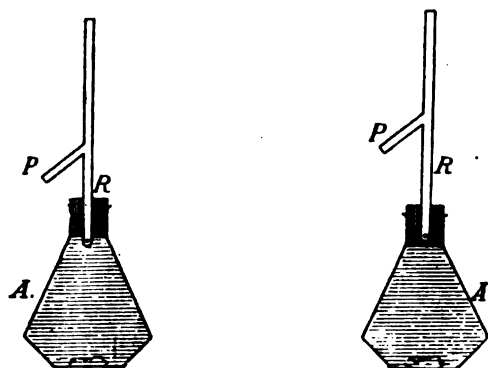


Fig. 18.

closed. To fill the flask a fine aluminum wire is put into it, like water to be tested is allowed to flow in as quickly as possible along the side, it is corked at once and the tube *R* raised so that the side opening is in the rubber cork, and the outer air fully excluded. The tube *R* is thoroughly washed with distilled water, the upper end joined to the graduated tube *B* and the side fork of *R* is connected with a reservoir of HCl (*S*) † by the rubber tube *N*, which is closed by a clamp. The rubber connections are tightly tied, then the sphere *K* emptied by lowering the mercury reservoir *D* and closing the cock *L*. The air which is now in *B*, by proper turning the cock *L* and raising the reservoir *P* again, may be driven out of the apparatus, after taking away the rubber con-

*Treadwell "Analyse der Passagier Mineralquellen."

†This figure is omitted.

nection to the Orsat tube. Repeating this operation several times, K is finally emptied. Now pressing the tubes R carefully into the cork so far that the side opening appears below it, the HCl finds its way into the flask A and there is a lively evolution of gas, and the mercury falls rapidly in B.* When it is about three-fourths full, the reservoir D is suddenly lowered and the cock L closed. In the meantime the Orsat tube O, full of potash (K_2O) has been connected with D and the gas is driven (noting the volume, temperature, and height of barometer) from D into it, by turning L and raising D.

Then the connection between A and B is restored and another lot of gas generated. If the gas comes too slow, the flask A may be warmed, under certain special precautions.

Finally when only a little gas is given off a few c.c. of HCl (1:2) are put into the flask A, and finally, more is added and boiled but with care that no water goes over into B.

After all the CO_2 of the expelled gas has been fully absorbed, and the amount of water vapor subtracted from the sum of the total readings, the volume of total CO_2 is thus obtained. The operation takes one-half to three-quarters of an hour.

Lime. The lime was titrated with 1-10 normal HCl, using methyl orange as indicator.

The partial pressure (amount of CO_2 in overlying atmosphere) is lessened, as was remarked at the beginning by replacing a part of the CO_2 over the fluid by air. The tubes r_2 and r_3 with their prolongations, t_1 and t_2 serve the purpose; these outside the bottles are bent at right angles and closed by rubber tube and clamp, and fit snugly into the hole of the cork, but can yet be moved up and down in the same.

The process is as follows: The ends of the rubber tube at t_1 and t_2 are taken off. The clamps q_1 opened and from t_1 and t_2 the air sucked with an air pump. If one wishes to lessen the partial pressure but slowly, the gas is replaced by air without admitting the air through the fluid. The partial pressure decreases much faster if the air is allowed to enter through the solution, after that diluting the atmosphere charged with CO_2 that rests on the surface of the water. Finally the apparatus is closed and in either case one must wait several days for equilibrium to be established.

*Care is to be taken that the pressure is less than an atmosphere.

1. Calcium bicarbonate.

For the details of process of formation and filtration without change of pressure from quicklime and water charged with CO_2 , reference must be made to the original Experiment 1. Solution was kept in a room of constant temperature 24 hours. The solution which stood under the pressure of one atmosphere CO_2 was analyzed four successive days and the total CO_2 and CaO found constant, to wit: 2.854 parts per thousand of CO_2 and 1.156 Ca CO_3 , of which 0.509 is CO_2 equivalent to 1.872 CaH (CO)_2 with 1.018 CO_3 .*

The lime was not quite pure, containing in 100 ccm water, in grams:

0.0005	CaSO_4
0.0006	SiO_2
0.0010	Fe_2O_3
0.0021	impurity

Experiment 2 was conducted with a CO_2 pressure of 67.9 mm mercury.† On the surface of the solution was to be observed a faint inappreciable crystalline secretion of calcium carbonate. It follows that from the partial pressure of 70 mm (when CO_2 is 9% of the atmosphere) up, the solubility of the bicarbonate increases too slowly to be determined in this interval with present apparatus.

Below this the separation of carbonate begins when by dilution of the CO_2 with air the pressure of CO_2 is lessened, and depends on the evaporation of the CO_2 from the water into the air. This reaction ceases when no more calcium is precipitated and the gas analyses show no increase in partial pressure. Numerous tests have shown that to determine equilibrium, the gas analysis is

*The detailed figuring is as follows:

(a) CO_2 , 92.67 cc. water used,

4 or 5 times repeated boiling gave	177.3 ccm. gas
After absorption with K O H	42.6
CO_2	134.7
Pressure 724.7 mm. mercury temperature	10°.4 C
Reduced to standard pressure (740mm.) and temperature 0°C=	121.74
Equivalent in 100 cm. of water	131.40
Milligrams CO_2	258.4
A repetition gave	258.3

(b) Ca . In all four cases, per 100 ccm. water 22.34 cc. 1-10 normal HCl of coefficient 1.0346 was used; i. e., 23.11 cc. 1-10 HCl corrected, corresponding to 115.6 CaCO_3 with 50.9 CO_2 or 187.2 $\text{CaH}_2 (\text{CO}_3)_2$ with 101.8 CO_2 .

100 cm. solution evaporated to dryness gave .....	.1180 g CO_3
By titration above .....	.1158
Indicating .....	.0025 impurity.

A fair correspondence.

†9.987 CO_2 in the air at $t=12.50$ and 726.1 mm. pressure.

NOTES ON THE ORIGIN OF MICHIGAN BOGLIMES. 207

surest, for a slight decrease in calcium in solution corresponds to a relatively great change of partial pressure, and if two successively performed gas analyses are alike, the solubility of the bicarbonate is alike, as test 3 showed. At the beginning of the test the atmosphere above the water contained 8.94% CO₂. Air was sucked in and the gas above the water at once tested. The CO₂ was but 3.47%. After a while a second sample of the gas as well as one of the water was investigated. The CO₂ had risen to 6.23%, nearly double, while the bicarbonate has dropped off about one part per liter. After this point the CO₂ and lime remained constant.*

Ca.	Per 1000.		% CO ₂	Pressure.
	Ca.	Bicarbonate.		
Experiment 2.....	.462	1.872	8.94	.....
	.463	1.876	3.47	.....
	.439	1.776	6.23	67.9
Experiment 3.....	.433	1.755	6.04	.....
	.433	1.755	6.02	.....

Treadwell and Reuter give the following other observations on the solubility of CaCO₃ in carbonated waters.

Grams CaCO ₃ in liter.	Tem.	Authority.
.7003.....	0°	Lassaigne Journ. p. Chem. 44, 84.
.8803.....	10	Lassaigne Journ. p. Chem. 44, 84.
.6700.....	.....	Bergmann Arch. Pharm. (1874) [3] 4 : 145.
1.8000.....	.....	Bischoff Jahr. Chem. phys. geol. (quicklime).
2.8000.....	.....	Bischoff Jahr. Chem. phys. geol. (quicklime).
2.5000.....	.....	Marchand, 2.64, (pure) from Caro.
1.0 to 1.5.....	.....	Struve, 2.64, (pure) from Caro.
3.0.....	.....	Caro inaugural dissertation.
.9832.....	21°	Warrington p = 7.483 mm.

*Details of figures are as follows:
Partial pressure P = p (percentage reduced to normal) × 7.60

Experiment 2. Zero point 2.2.	Height of mercury in barometer tube of apparatus.	Temperature in degrees centigrade.	Barometer in mm.
Initial volume.....	58.0	12.5	726.1
After absorption of CO ₂	127.7	12.5	726.1

Tension of water vapor at 12.50 5' = 10.8.
Initial volume stood under the pressure 726.1 - (55.8 + 10.8) = 659.5.
Gas — CO₂ stood under the pressure 726.1 - (121.5 + 108) = 593.8.
Therefore percent air = 659.5 divided by 593.8 × 100 = 90.02 and percent CO₂ = 9.98.

According to these data the solubility of calcium carbonate in carbonated waters varies from 0.7003 to 3.0 grams per liter. The statements of Bischoff that the solubility of CaCO_3 is dependent on the purity of the material which furnishes the CaO or CO_2 can not be confirmed, but at 15°C , saturated calcium bicarbonate solutions gave, whether made of pure or impure limestone, from 1.13 to 1.17 grams per liter of CaCO_3 . At 13.2°C . the solubility was 1.31 grams per liter for the CaCO_3 from common quicklime, and 1.30 grams per liter for the pure material. At a temperature of 2.8°C there was 1.45 CaCO_3 in the liter, showing a greater solubility at the cooler temperature. Long standing produced no increase in calcium.

A study of the solubility of calcium carbonate from an analogous point of view is presented by a work of Schloesing Compt. Rend. 74:1552. His table is as follows, but he does not describe how the partial pressure was computed:

Pressure of CO_2 in atmospheres, $t = 16^\circ$.	Total CaCO_3 per thousand.	Total CO_2 .
0.000504.....	.0746	.06096
0.000808.....	.0850	.07211
0.00533.....	.1372	.1230
0.01857.....	.2231	.2184
0.0282.....	.2966	.3104
0.05008.....	.3800	.40863
0.1422.....	.537	.....
0.2538.....	.6334	1.0720
0.4167.....	.7875	1.500
0.5533.....	.8865	1.8460
0.7297.....	.9720	2.2700
0.9841.....	1.0860	2.8649

We may also add as of interest to us in this connection the following extracts from Roth's Chemical Geology.

Vol. 1, p. 44, solubility of gases and other substances in water.

Baumert found in the air absorbed by rain water ($t=11.4^\circ\text{C}$; after a long rain) 1.77 volumes CO_2 , 33.76 O, 64.47 N, while in atmospheric air there is but 1 vol. CO_2 to 628 of O.

Bunsen says that 1 volume water absorbs at 760 mm (atmospheric) pressure (i. e. about 1 atmosphere):

	At 10°C .	At 15°C .	At 20°C .
O.....	1.03250 or 1	0.02989	0.02836
CO_2	1.1847 36.4	1.0020 or 33.5	0.9014 or 31.8
N.....	0.01607 or 0.50	0.01478 0.49	0.11403 or 0.4

Thus more CO_2 is absorbed at low temperatures. The air free from CO_2 absorbed at 23°C consists of 34.91 volumes N and 65.09 O.

Bunsen estimates from the power of absorption the ratio of the gasts in rain water, supposing atmospheric air to be 20.951 O and 79.007 N and 0.042 CO_2 , as follows:

	5° C.	10° C (50° F.)	15° C. (59° F.)	20° C.
CO_2	2.68	2.46	2.26	2.14
O.....	33.97	34.05	34.12	34.17
N.....	63.35	63.49	63.62	63.69

Under otherwise similar relations the amount, of absorbed gas is proportioned to the pressure. Peligot found in 1857 2.4 per cent CO_2 by volume in the air absorbed by rain water.

P. 45. According to Boussingault and Levy 100 volumes of air from a soil not rich in humus and not manured for a long time, contain at least 25 times, that from humus rich soil 90 times, and that from recently manured soils as much as 250 times, as much CO_2 as atmospheric air,—the maximum in 100 volumes of air 9.74.

Pettenkofer found in the ground air of Munich down to 4 meters depth a maximum of 1.838 per cent CO_2 .

P. 48. Solubility of Ca CO_3 .

Fresenius: 1 part in 10,600 cold or 8,834 boiling water; Graham, 0.0343; Bineau, 0.016 to 0.02; Cruse, 0.036; Peligot, 0.020; Schloessing, 0.0131 in 1,000. If at 15°C water takes up 1 volume of CO_2 (i. e. about 0.2% by increase of pressure and lower temperature more), the amount of carbonate dissolved increases. In water saturated with CO_2 (which does not occur in nature) is dissolved in 1,000 parts of water, according to:

Bischof of chalk.....	9 to 10
Cossa of chalk of Luneburg (18° , 740 mm)	.835
Carrara marble (7.5° to 9.5° , 753 mm)....	1.181
Cossa Carrara marble ($20.5-22^\circ$, 741— 746 mm).....	.9487
Cossa Carrara marble ($26-28^\circ$, 737— 742 mm).....	.855
Calcite 12° 754.2 mm.....	1.217
Iceland spar 18° , 735.1 mm pressure.....	.970
Precipitated CaCO_3 at 18° and 735.1 mm..	.950
Boutron and Boudet (several atmos- pheres pressure of CO_2).....	1.16

According to Warrington at 13° and 747.3 mm. pressure water with 1% ammonium chloride dissolves 1.050 CaCO₃.

If to a solution of CaCO₃ in CO₂ water MgCl₂ is added the solution will stand weeks and can even be boiled without clouding. By continued evaporation magnesium carbonate is precipitated.

According to T. S. Hunt the solubility of CaCO₃ is increased also by addition of sodic or magnesian sulphate, because bicarbonates of soda respectively magnesia form.

According to Northcote, 1,000 parts of saturated salt solution contain 1.77 CaCO₃.

P. 50. *Magnesia carbonate* is somewhat more soluble in carbonated water than calcium carbonate. Merckell's results are:

In 1,000 parts at 50° C. under a pressure of CO₂ of:

1 atmosphere	2	3	4.5	6
1.31	1.34	7.5	9.0	13.2
Cossa 18°, 750 mm pressure, from magnesite.....	.115			
Bischof, 750 mm, pressure from magnesite.....	.049			
from pure magnesia.....	.135			

P. 51. Fresh precipitated magnesia carbonate is quite soluble in a solution of the sulphate and precipitates Ca CO₃ from solution in carbonated waters.

Vol. III, p. 417 Engel and Ville, under pressure of 1 atmosphere CO₂, the solubility varies with the temperatures, 19.°5' C. 29°.3 C. 82° C. as follows: 257.9, 219.95, 49.0; the presence of alkaline chlorides, sulphates, and carbonates and magnesia salt increases the solubility of magnesium carbonate.

Dolomite. Vol. I, p. 52 Cossa at 18° C. 750 mm. pressure, 1,000 parts of water dissolve:

of dolomite (CaMg (CO ₃)) ₂.....	.310
Of mesitine FeMg (CO ₃) ₂.....	.075
At 16° C, 758 mm carbonated water dissolves	
of (Mg Fe ₃ C ₄ O ₁₂).....	.115
A. Kupffer, of dolomite .....	.2967
<i>Siderite</i> FeCO ₃ . Wagner, at 4 or 5 Atm. pressure of CO ₂ FeCO ₃.....	.725
Cossa 18°, 760 mm.....	.720
Bischof .....	.60755
K. von Hauer, usual pressure, iron dust of precipitate .....	.91

Carbonates of alkalies lessened solubility.

Iron Carbonate.

III, p. 417, J. Ville found in carbonated water.. 1.39
E. Ludwig Wilhelm's quelle water..... 0.9648

Schloesing worked thus: crystallized pure calcium carbonate was suspended in water and through the fluid air charged with CO_2 passed until gravimetrically no increase in calcium carbonate could be detected. But there is probably an error in calculation, for Schloesing in the strongly carbonated solution, assumes carbonate together with bicarbonate to be present. For instance, he computes:

1. CaCO_3 (neutral) according to special tests of solubility .....	.0131 g in liter
All calcium as carbonate.....	.360
<hr/>	
Difference calcium carbonate existing as bicarbonate .....	.3469

Accordingly he refers to the three following parts of CO_2 :

CO_2 in the neutral calcium carbonate.....	.00576
CO_2 in the bicarbonate.....	.30530
CO_2 free .....	.09757
	<hr/>
	.40863

Caro denies the existence of calcium in carbonate, from the following test. A solution of calcium bicarbonate with excess of CO_2 was allowed to stay exposed to the air until calcium carbonate began to form at the surface, and then the CaO and CO_2 of the clear solution determined. Caro gives the following figures: 5 cm. solution contains:

$0.00270 \text{ CaCO}_3 = 0.0015176 + 0.0011924 \text{ CO}_2$, or in grams per kilogram:

$0.540 \text{ CaCO}_3 = 0.35352 \text{ plus } 0.23848 \text{ CO}_2$.

"Total CO_2 was determined by precipitation of 5 ccm. with ammonical BaCl_2 . The computed CO_2 is 0.0142 gr. (.142 gr. per 100 cm.).

Caro's result is thus: Combined $\text{CO}_2 = 0.0011924 \text{ g.}$, half combined and free = 0.0142 g.

The ratio of two numbers is 1 : 10, which certainly points to the presence of *calcium bicarbonate* and much free CO_2 .

A series of tests, Nos. 3 to 12, showed that the three values, partial pressure in per cent at 0° C. and 760 mm. pressure, amount of calcium bicarbonate and free CO₂ decrease together so that when the first and last become zero the total CO₂ is just equal to the amount needed for calcium bicarbonate. From this the conclusion is justified that calcium bicarbonate is a permanent salt in solution, whose solubility is for the mean barometric pressure at Zurich and the temperature of 15° 0.38509 per liter. Two tables and curves are given, showing the solubility of this salt, first as a function of a partial pressure, and second, as a function of the amount of free CO dissolved. We do not repeat the curves, which can be constructed from the table below, of the original figures 5 and 6.

SOLUBILITY OF CaO IN BICARBONATED WATER AT 15° C. — 59° F. AND 760 mm. PRESSURE.

In Air.			In Water (parts per thousand).						
Test.	% CO ₂ .	Pressure of CO ₂ .	Free CO ₂ .	Calcium bicarbonate.	Fixed CO ₂ .	CaCO ₃ .	Ca.	Total CO ₂ .	CaO.
1.....	100.00	760	1.574	1.872	.509	1.156	.462	2.587	.647
2.....	8.94	67.9	1.574	1.872	.509	1.156	.462	2.587	.647
3.....	6.04	45.9	.863	1.755	.477	1.063	.433	1.817	.606
4.....	5.45	41.4	.528	1.597	.434	.986	.394	1.396	.552
5.....	2.18	16.6	.485	1.540	.418	.951	.380	1.321	.533
6.....	1.89	14.4	.347	1.492	.405	.921	.368	1.157	.516
7.....	1.72	13.1	.243	1.331	.362	.822	.329	.967	.440
8.....	0.79	6.0	.145	1.249	.339	.771	.308	.823	.432
9.....	0.41	3.1	.047	.821	.223	.607	.203	.493	.284
10.....	0.25	1.9	.029	.595	.162	.368	.147	.353	.206
11.....	0.08	0.6	.....	.402	.109	.248	.099	.214	.139
12.....	.....	.....	.....	.385	.105	.238	.095	.211	.133
13.....	.....	.....	.....	.385	.105	.238	.095	.211	.133
14.....	.....	.....	.....	.385	.105	.238	.095	.210	.133

The data given above lead to the inference that calcium bicarbonate may exist in very dilute solution.

In consequence, it was of interest to determine the electric conductivity of this salt, for Kuster says* that the bicarbonate in very dilute solutions is hydrolytically separated since its solution colors phenolphthalein feebly red. This was found true, but the result of electric tests was that "the conductivity reached no maximum, even in the greatest dilution, as is usually the case with salts that are hydrolytically broken up," and bicarbonate of potash behaved in the same way.

*Z. Anorg. Chem. 13, 127.

Calcium bicarbonate in solution with NaCl.

From Kippenberger's tests it appears that calcium carbonate is about three times more soluble in concentrated salt solutions than in water. This greater solubility is probably dependent on the formation of double salts. Therefore it was to be expected that these double salts, like Karnallite, would be fully decomposed in dilute solution, so that the solution of calcium carbonate in dilute solutions of salt would be similar to that in pure water, and a similar behavior should be found for the bicarbonate.

Tests performed as for pure water on dilute saline solutions charged with CO_2 , which contained 5 grams per liter NaCl, result as follows:

ABSTRACT OF TABLES 3 AND 4.

				0.41	0.50	3.16	6.07	11.47	16.95	CO_2 at 0° and 760 mm in gas
.082	.081	.083	.086	3.4	3.8	24.0	46.1	87.2	128.8	pressure of CO_2
.090	.089	.092	.095	.121	.182	.292	.368	.529	.539	Ca
				.133	.201	.321	.405	.582	.593	CO_2 corresponding to
.205	.203	.208	.216	.303	.456	.730	.921	.1323	1.348	CaCO_3
.332	.329	.337	.349	.409	.739	.1183	.1492	.2143	2.184	CaCO_3
				.003	.027	.135	.235	.1101	1.325	Bicarbonate
										Free CO_2

From this (comparing with tables 1 and 2), it is apparent that the solubility of calcium bicarbonate is but little influenced by the salt.

Figures 7 and 8 of the original paper showed the solubility as function of partial pressure, and as function of percentage of CO_2 .

II. Magnesia bicarbonate.

No new principles involved. (Details of experiments omitted.)

1. Without alteration of the partial pressure (of 1 atmosphere CO_2) the CO_2 and MgO remained constant down to experiment 4, when the amount of CO_2 ceased to be enough to form bicarbonate of magnesia with the MgO present.

Fig. 9 and Fig. 10 (should be 8 and 9) showed the solubility of the bicarbonate as function of partial pressure and total CO_2 8 in mg.

The result is that magnesium bicarbonate does not exist by itself without a marked excess of free CO_2 dissolved in the water. The partial pressure needful thereto, corresponds to between 2° and 4° CO_2 . If the partial pressure is less, the solution loses all of the free CO_2 with a part of the half combined and a mixture of carbonate and bicarbonate results. When the partial pressure sinks to 0 at

average pressure and at 15° C, we have 0.6410 grs. magnesium carbonate and 1.9540 grs. magnesium bicarbonate per liter.

References to the solubility of magnesium bicarbonate are very rare. Cossa and Kippenberger assume its presence only when there is much free CO₂. Merkel is cited in Roth.

IV. Sodium bicarbonate.

To close the investigation, the presence of sodium bicarbonate in dilute solution was tested. The phenolphthalein test shows that the bicarbonate little by little gives off CO₂, and the solution becomes stronger in carbonate.

Referring to Kuster's work indicating that sodium bicarbonate, by its effect in turning phenolphthalein red, is decomposed at moderate temperatures, the effect vanishing at 0° F, it is to be remarked that solutions of bicarbonate left long standing do the same, and the effect does not disappear at 0°, which leads to the inference that it has lost CO₂, and a series of four tests show this to be true.

We have given above, all the data we have been able to find on the solubilities of the carbonates for different temperatures and pressures. Now for the actual temperatures and pressures, the map figured herewith (Fig. 19), gives some data as to the mean annual temperatures by the isotherms or lines which have the same annual temperature. Upon the map are also placed the temperatures of certain flowing wells, in degrees Fahrenheit.

It appears that the temperature of ground water is usually not far from 49°, increasing according to the depth of the source quite irregularly, but at times as much as 1° in 40 feet. The farther north a place is, other things being equal, the lower the temperature. But it probably goes hardly below 45°, being more or less above that according to the amount of blanketing effect that the snow exerts, and the depth of the source.

The water of all our deep lakes is cool, and in the bottoms of the deeper lakes it will often be permanently cooler than the ground-water temperature. Hence chemical precipitation can never occur in the lake more than half the year, and it will not occur at great depths. Boglime, however, occurs more in lakes originally deep, than in lakes originally shallow. Still it appears to be generally true that in Michigan the marl is thicker in the shallow water at

the margin, and Wesenberg-Lund reports the same to be true in Denmark. This can, however, be easily explained under either theory, that of organic or chemical precipitation. But it is curious to remark that in Indiana the geologist reports* not only a deepening of the marl towards the deeper water, but a more widespread

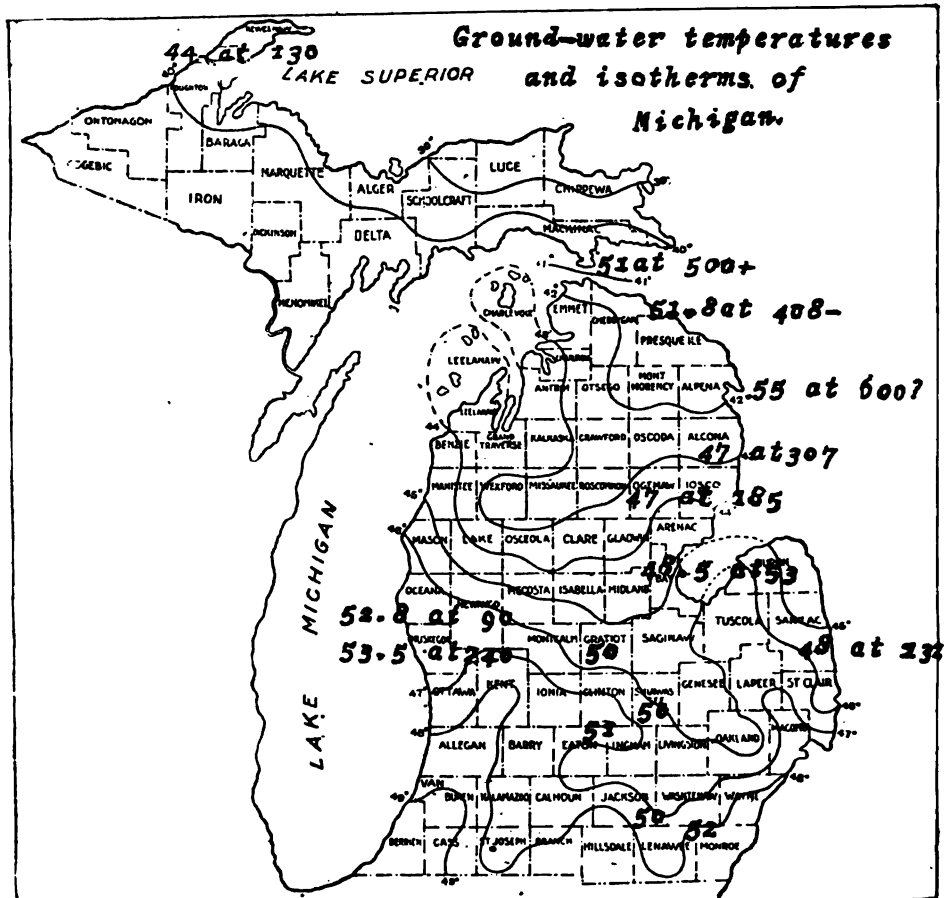


FIG. 4.—Distribution of average mean temperature in Michigan.

Fig. 19. Reproduced from Water Supply paper No. 80. Fig. 4, with some observations on the temperatures of flowing wells.

distribution, a fact which hardly agrees with their theory of the origin of the lime.

Not only will the spring water that enters the lake be cool and under pressure at the bottom so that it will not lose its carbon dioxide nor calcium carbonate there, but as it approaches the sur-

*25th Annual Report, 1900, p. 45.

face it is liable to be diluted with rain and surface water, which as all tests and* analyses show, are far from saturated with bicarbonates† and a dilution with only 10% of rain-water would keep in solution all the calcium carbonate of any ground water of which we know. Mr. Hale has pointed out that marl is liable to occur most in the uppermost of a series of lakes, into which presumably less surface water would enter, and this is a distinct point in favor of the theory of chemical precipitation. But it is by no means confined to such lakes. Davis' observation, that in certain lime depositing lakes, the outflow is practically equal to the inflow, does not necessarily mean that the evaporation is too small to be noticed,‡ but merely that it is nearly balanced by subterranean springs and direct rainfall. It does, however, make it almost certain that there is enough dilution of ground water springs to prevent direct chemical precipitation.

All winter again, the water under the ice is colder than the ground water, and the escape of CO_2 is prevented. There can be no direct chemical precipitation. In the spring the influx of snow water must dilute the spring water and prevent precipitation.

Only after the hot dry weather of summer has evaporated and heated the lake to saturation point could, if ever, precipitation begin, but it seems doubtful if it could get that far.§

Considerations like the above had made the origin of the bog-limes by chemical precipitation very doubtful to me, even before Messrs. Davis and Hale made it so clear that organic life was the precipitating agent in some cases, at any rate. In fact such doubts led me to suggest to them their lines of work.

Mr. Davis' discovery of calcium succinate $\text{Ca}=\text{O}_2=(\text{C}_4\text{H}_4\text{O}_2)$, in Chara, and its lime secretions yield a new test of the origin of the fresh water limes.

Until this very peculiar salt is shown to be formed in some other way, it is a safe presumption that chara, or at least plant life has contributed largely to lime deposits containing it. It is

*See also Water Supply Paper No. 31, analyses 35 to 45, and ante pp. 46 and 118.

†While as shown above rain-water selectively absorbs considerable CO_2 from the air.

‡If we look at the figures given in the "Meteorological Chart of the Great Lakes for the Season of 1899," Vol. II, No. 9, of the Weather Bureau publications, p. 21, we see that the evaporation must be between 20 and 36 inches, and the precipitation is from 4 inches to 20 inches more.

§Yet the number of facts that must be known, accurately, evaporation, ground water supply, surface water supply, temperatures, and co-solubilities under a large range of conditions, prevent our saying absolutely that it could not occur. In fact, in such a case as the marl referred to by Mr. Hale at Corrinne, where the whole lake dries up, it must.

also found that, as Hale has remarked, organic matter always accompanies even the purest marls. Moreover, it seems to be true that in a marl analysis, in which the CaO, MgO, and CO₂ are separately and independently determined, there is never enough carbonic acid to satisfy the caustic lime and magnesia,* even after making all allowance for the presence of calcium sulphate. While in clayey marls it might be supposed that calcium and magnesium silicates were present, in many of the purer ones the effect is too great to be thus explained, and we are forced to believe that we have the lime united to an organic acid, probably this succinic acid.

It is not uncommon in commercial marl analyses to figure from the CaO and MgO the amount of carbonates, and for many purposes this is sufficient, but in such cases the chances are that the amount of carbonates is overestimated and the amount of organic matter underestimated some 2%.

§ 3. Microscopic investigations.

Although it might seem that the subject of the origin of boglime had been pretty thoroughly threshed out, it must be kept in mind that, in view of the number of causes that are competent under proper conditions to throw down lime, no available light should be neglected. It seemed possible that a study of the microstructure of the lime with the petrographic microscope might be an aid. For comparison with them, some artificial precipitates were made for study.

(a) Microscopic precipitate by loss of CO₂ and heating.

I took a sample of water from the flowing well at the end of Hazel street, Lansing, close to the bank of Cedar river.† This well flows into the air about six feet above the usual river level and has about two feet free jet. The depth is 340 feet, but the water doubtless comes in mainly at much less depth. Within half an hour of the time of taking the water, it was heated to the simmering point, when of course the CO₂ was practically lost. A film was seen floating on the top,—not a continuous coating, but a lot of calcite crystals. With an enlargement of 150 diameters their crystalline character was very apparent. Hexagonal outlines were plain. They were not all simple forms, nor always the same form. Rhomb faces and hexagonal outlines were common (Fig. 20), but

*For instance, the average amount of CO₂ which Prof. F. S. Keszle found by analysis in thirty marl analyses in which CO₂ ranged from 27.13% to 44.60% was 36.28% while the amount of CO₂ required by the weights of CaO and MgO in the marl was in each case higher, the average being 38.30%, a good 2% more.

†Temperature 50.8° F.

simple rhombohedra were not the prevalent form. In relative dimensions and habit they resemble often Fig. 21 of the Appendix to Part II of Vol. VI of our reports, or figures 11 and 13 of the calcite illustrations in Dana's System of Mineralogy. Though they are too small (about 0.02 mm) to be exactly determined, the prism or a very long scalenohedron, and the terminal rhombohedron— $\frac{1}{2}$ are quite probably present. The optical properties leave no doubt that they are calcite. When transmitting the ordinary ray they

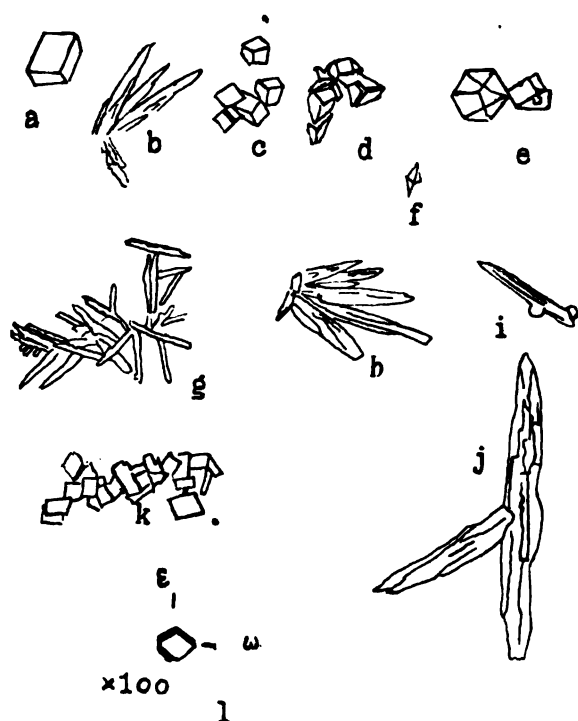


Fig. 20. Crystals produced by evaporation.

have much higher refraction than that of the balsam used for mounting ($n=1.521$), while with the extraordinary ray their index is very close to that of the balsam,—just a shade less, as it should be. (1.49) The directions of + and — extinction parallel to the diagonals of the rhomb faces are characteristic (Fig. 20). One twin with the twinning face probably— $\frac{1}{2}$ was observed. In mounting these crystals a second crop was formed as the water around them evaporated, considerably smaller, being half or quarter the size, and spindle-shaped, like dog-tooth spar (Fig. 20f), and the

forms illustrated on Plate XI of the Appendix to Vol. VI, Part II, and Dana's figures 15 to 20.

No marl seen consists to any considerable degree of similar material. Had it been present in quantity, I do not think I could have failed to recognize it. It must be said, however, that every marl had been more or less dried, and therefore a certain amount of secondary chemical precipitation from the hard water of the lakes was to be expected. As a matter of fact, I noticed no material that need necessarily be ascribed even to this source.

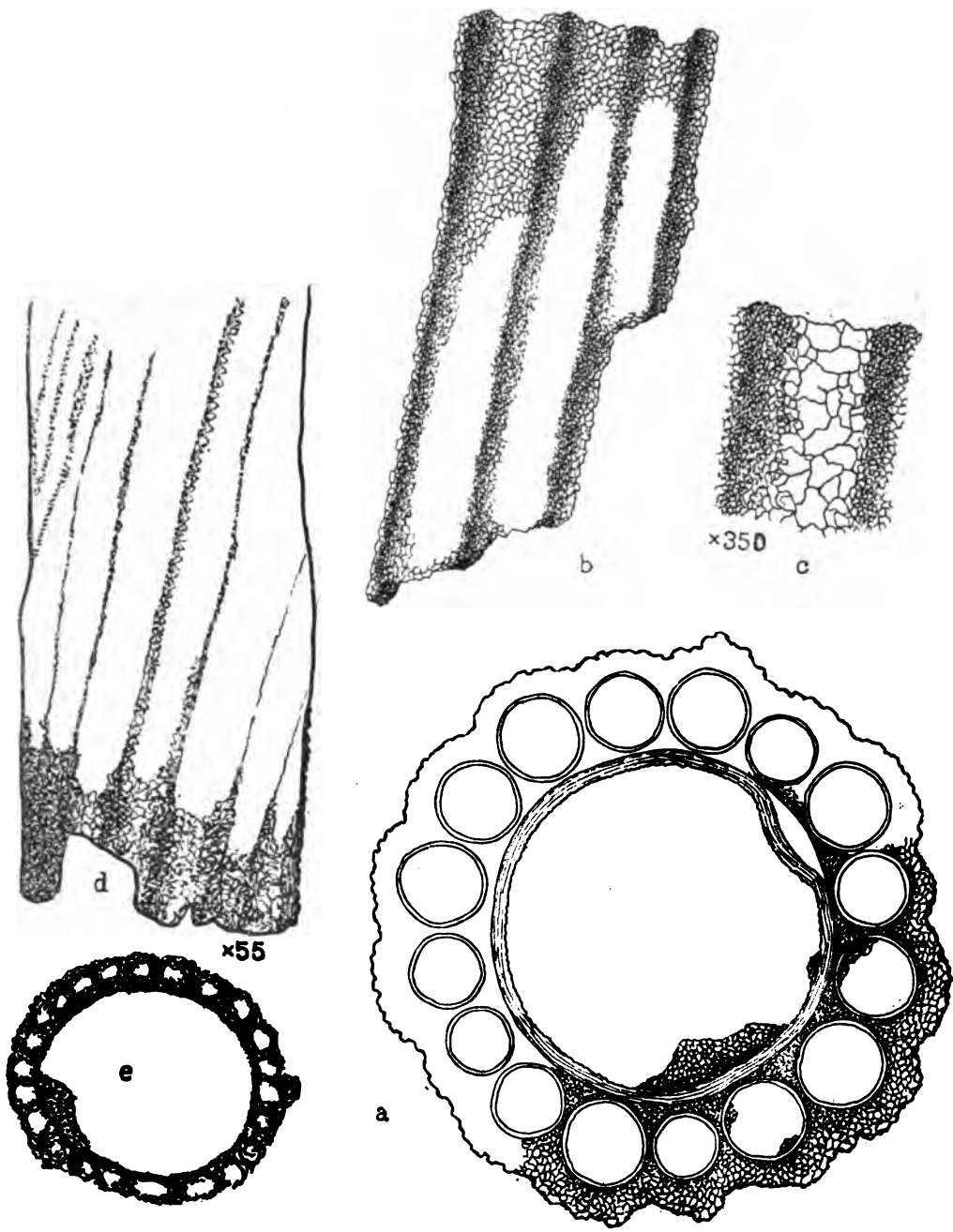
(b) Precipitate by evaporation.

I also allowed drops of water of the artesian well used in the Hollister block (which is 150 feet deep in white sandstone of the coal measures and probably similar in chemical character to the previous well and analyses Nos. 238 and 239 of U. S. Geol. Sur. Paper No. 31), to evaporate. In one drop the dimensions of the larger crystals are about 0.005 mm and less, about a three hundredth of a millimeter. In so minute crystals it is hard to measure angles accurately, but it appeared that a termination of the fundamental rhombohedron was combined with prismatic or acute scalenohedral faces.

In Figure 20, groups a to j were drawn by C. A. Davis from some Alma well water. I think that b and g, h, i, and j, are groups of gypsum crystals, while a, c, d, e, and k, appear to be mainly rhombohedral calcite, and f is plainly a scalenohedron. In l we have a crystal drawn by myself with the camer lucida with some pains to get the angles right, and the optical orientation indicated. The contrast in relief brought out by rotating the crystals immersed in balsam above a single nicol is very striking and characteristic.

(c) Chara fragments.

The calcareous Chara stems have a hollow core surrounded by a single slightly twisted row of elongate cells. The diameter is commonly about half a millimeter. The lines between the cells are continuous and produce the effect of slightly spiral ribs. This is shown in Fig. d of Plate XVI. Fragments of chara therefore, like figures b and c appear ribbed. Close to the ribs the granulation of the calcareous aggregates is very fine, while between it grows coarser,—up to 0.02 mm. The boundary between the various areas or patches of uniform polarization color appears vague or crenulated. This interdigiting effect or crenulation is especially shown



MICROSCOPICALLY ENLARGED FRAGMENTS AND SECTIONS OF CHARA.

in c, and sometimes needs the use of crossed nicols to bring it out. Even very small fragments show patches of different polarization colors. Sections a and e are cross-sections of chara stems drawn by Mr. B. O. Longyear and myself. Such sections are hard to prepare and seem never to occur accidentally. The other sections b to d are such as will ordinarily be found in looking at a sample of marl.

(d) Blue green algae.

The apparently calcareous pebbles which are really concretions of calcium carbonate thrown down or out by *Schizothrix*, have already been described by Davis. Similar pebbles are noted as occurring in the marl in certain horizons at Goose Lake, from which the Peninsular plant take their marl. The pebbles in marl referred to in the discussion of Prof. Fall's paper before the Engineering Society are probably similar, and the calcareous coating on dead branches and shells also. The "pebbles" on the southeast side of Zukey Lake at Lakelands, which turn brown on the side exposed to the light, are of the same nature.

A cross-section of such a "pebble" or concretion shows a faintly radiating structure. Under the microscope I have not been able to discern this, but instead, there appears to be a cloudy aggregate of irregular calcite, not sharply crystalline nor coarse grained, not over a hundredth of a millimeter at the outside.

There is not very much that is characteristic about it, and very much of the commercial boglime deposits is precisely similar.

Near the Cottage Grove Higgins Lake resort, not only are the upper sides of pebbles overgrown with warty deposits of these algae, but the bottom sand is cemented in a layer about 3 mm thick, brown on the upper side and greenish on the lower.

(e) Shell structure.

The shells which occur in the boglimes are as Walker's list shows, mainly (bivalves) pelecypods or gastropods (snails). Whatever the genus, and whether the structure be foliated or prismatic, aragonite or calcite, the ground up shells should show, and do as a matter of fact show a fibrous structure under the microscope. Larger pieces are commonly composed of bundles of fibres, more or less opaque, owing to the interlamination of material of different refraction. The direction of extinction is usually either parallel or varies according to some law, and there is a pronounced organic structure which can hardly be mistaken, but which varies of course,

according to the species. I do not think, however, that any considerable amount of such material could escape detection under the microscope. It generally forms an unimportant part of the commercial marl or boglime deposits.

(f) Limestone flour.

What is called clay in Michigan, is, so far as the glacial clays are concerned, more properly rock flour, and contains a great deal of finely divided quartz and other minerals, being by no means merely a hydrous alumina silicate. Inasmuch as the limestones and dolomites form a large part of the subsurface or bedrock of the State, and of Canada to the northeast, the almost universal presence of lime in the clays, which are thus rendered properly marls, is quite natural. Now it is not inconceivable that, as Mr. Parmelee has suggested, in a region of limestone rocks sedimentary clay-like deposits might form, aided perhaps by the greater weight of the carbonates, in which lime would predominate to almost any extent. Such clays as the following analyzed by Prof. Fall, from Alcona county are very largely limestone, though in them magnesia is present in quantity, and this we should expect would be generally true. A typical till clay from the old brickyard southeast of Harrisville, Alcona county, containing some small limestone fragments, is composed as follows:

Free sand.....	11.53	11.53	Sand.
Combined silica.....	25.71		
Oxide of aluminum.....	7.08		
Oxide of iron.....	3.99		
Organic matter, basic water.....	3.46		
Difference chiefly alkalis.....	2.60	42.84	Clayey matter.
Calcium oxide.....	1.70		
Magnesium oxide.....	6.52		
Carbon dioxide.....	21.00	45.22	Limestone.
Sulphur anhydride.....	0.41	0.41	In pyrite or gypsum.
		100.00	

Examined under the microscope, such clays, which as we see are nearly half limestone flour, show a good deal of material which is almost indistinguishable from the alga deposits or the commercial marls. But the material is in general, more brown and opaque, contains more or less angular quartz, and almost always fragments of limestone which are over 0.01 mm in diameter,—frequently 0.05 to 0.08 and larger. Such fragments are absent in the marl, and this is the best distinction I can at present make. This is not very satisfactory. It seems quite possible that there might be quite an amount of sedimentary lime material in a bog lime, before we could

separate it microscopically from materials of another origin, organic or otherwise. It seems likely that the rise in magnesia to which Hale refers is fully as sensitive a test of the admixture of clay marl in a boglime as microscopic examination. The calcareous clays become much harder when dry, and even when wet again, only very slowly break down.

§ 4. Conclusions.

It appears, therefore, that any appreciable mixture of lime sediment does not produce the quality of bog lime which is desired for Portland cement manufacture. While a continual accumulation of boglime or marl requires a continual supply of lime which is furnished in the hard water of the springs, yet the animal and vegetable life of the lakes never allows this to accumulate to the point of chemical precipitation of the bicarbonate, but it is deposited through organic processes. In this the Characeæ play a conspicuous part, especially in the purer marls. More minute algae may have, collectively, greater and more widespread importance. In fact, microscopic examination seems to indicate this. The role of animal life is usually quite subordinate.

Notes on the microscopic examination of the different marls will be found in connection with the description of the different deposits in the next chapter.

CHAPTER IX.

LIST OF LOCALITIES AND MILLS.

§ 1. Introduction.

The object of this chapter is to give as full a list as conveniently could be made both of the Portland Cement mills actually at work and the materials that they use, and also of the plants that have been planned and materials prospected as well.

In description of the manufacturing plants, it must be remembered that the interest of the geologist is in the first place in the raw materials, and for farther discussion of the details of manufacture we must refer to Lathbury and Spackman of Philadelphia on engineering practice, the Detroit Journal of Wednesday, April 16, 1902, the nineteenth annual report of the Labor Commissioner, and professional journals like Cement, Cement and Engineering News, Stone, etc. Still we cannot thoroughly treat the raw materials without also considering the processes of manufacture to which they are adapted. We have also thought it would add considerably to the value of the report, to add a few statistics, for which we have to thank the Secretary of State and the Commissioner of Labor, to whose department such matters belong. A large amount of material is derived from the printed circulars and prospectuses of the various companies, or private correspondence with the same. It is, however, almost wholly from signed reports of reputable engineers, and is duly credited. Occasional comments which may be helpful by way of comparison are added.

Alpena Portland Cement Co.

Organized Aug. 9, 1899; capital, \$500,000. The officers and directors of the company are: F. W. Gilchrist, president; William B. Comstock, vice-president; George J. Robinson, secretary; A. M. Fletcher, treasurer; W. H. Johnson, auditor; John Monaghan, C. H. Reynolds, Water S. Russell, J. H. Cobb, attorney; F. M. Haldeman,

superintendent. Mill located just east of Alpena on the shores of Thunder Bay. A thousand foot pier gives water transportation, and the Detroit and Mackinac R. R. also runs to the mill. This was the first mill using limestone for the calcium instead of bog lime. It is the Alpena limestone close to the mill and belongs in the Traverse group, and corresponds somewhere nearly to the Encrinal limestone of the Hamilton of New York State. Not all of the bed is equally pure, however, and Dr. A. W. Grabau, who has made a particular study of the conditions for us, reports that the old coral reefs which occur in the bed furnish the purest calcium carbonate.* This is a very important result, for these coralline parts are easily recognized. The limestone is also used, especially the purer part, for the purification of sugar, and the report of the beet sugar chemists confirms the analyses of the local chemists, that at times the limestone is practically pure CaCO_3 . This is one of the plants which have the advantage of using a local shale clay.

"The raw materials are very economically handled. The clay brought from the beds to the north is piled in great bins in the clay storage house. This house is 225 by 60 feet in dimensions and will hold clay sufficient for 60,000 barrels of cement. From the quarries to the plant, a distance of 800 feet, tracks on which are run cable cars are laid through the clay shed. Here, each car of rock, as it passes through, is weighed, analysis having been made, and the correct amount of clay is added to make a perfect cement mixture. The cars then run to the mill and their contents are dumped into the crushers.

"The materials then pass through the crushers, rolls, ball mills and tube mills automatically, being ground finer and more thoroughly mixed during each process. During the wet grinding process, water is added in the ball mills and the final and finishing mixing is done by the tube mills, which contain imported flint pebbles. The action of these against the wet mixture, produced by the revolutions of the mill, reduces it to a slurry. Then the mixture passes into correction tanks, from which samples are taken by the chemists and tests are made to guard against error. The contents of each tank are corrected before the slurry is allowed to leave it. There are 12 mixing tanks, each 14 by 16 feet high and with sufficient capacity to each hold enough slurry for 250 barrels of cement.

"This mixture carries about 33 per cent of water which makes the resultant process better. Marl and clay mixture must necessarily carry a higher degree of moisture than with the dry process. The kiln capacity is much greater where lime rock is used,

*Annual report for 1901, pp. 174 to 191, especially page 178.

as there is less water to drive out of the material before it is calcined. At Alpena the rotaries each have a daily capacity of from 140 to 150 barrels of cement as against 100 by those using marl.

"From the storage tanks the slurry is fed into the rotary kilns. The fuel used in these kilns is powdered coal, prepared by drying and grinding, and is fed into the kilns by an air blast. The kilns are taken care of by experienced burners. From the kilns the cement clinker is discharged into conveyors and carried to the clinker room to cool. Six rotaries are in constant operation and the daily capacity reaches 1,000 barrels of cement. From the clinker room the material passes to the grinding machinery, consisting of rolls, ball mills and tube mills—the chemist takes the ground cement at this point and tests it for fineness, after which it is conveyed to the stock house, which has a capacity of 50,000 barrels, where it is allowed to season and then packed for shipment. Before shipment the chemical department makes a thorough test of the finished product for specific gravity, constancy of volume, soundness, tensile strength and setting time, and the cement is shipped only as certified by them to be in proper condition for immediate use.

"The dimensions of the various buildings are as follows: Stock house, 240 by 100 feet, making about 24,000 square feet of floor space; mixing and kiln building, 259 by 105; cement grinding room, 190 by 105. In addition to these, there is a thoroughly equipped cooper shop, machine shop and round house."

Although they are not at present using the bog lime it may be of interest to give the analysis of it as well as of their shale. It comes from Middle Lake, on Sec. 18, T. 32 N., R. 9 E., about seven miles north of the mill, where the company own a thousand acres tract including also their shale clay beds.

BOGLIME.

Calcium carbonate	92.91
Magnesium carbonate	1.89
Silica	tr.
Ferric oxide	0.53
Alumina	0.21
Sulphuric anhydride	tr.
Organic matter .....	.80
Water, etc.	2.01
	<hr/>
	99.87

CLAY SHALE.

CaO ($\text{CaCO}_3 = 4.48$)	2.51
MgO .....	.65
Silica	61.09
Ferric oxide	6.78
Alumina	19.19
Sulphuric anhydride	1.42
Water and CO_2	5.13
Potassium oxide	1.80
Sodium oxide	1.36

 99.93

Some of these shales and clays around Alpena will doubtless make good face and even paving brick.

The rocks around Alpena have been quite fully described by A. W. Grabau* in the Annual Report for 1901, and will before long be subject of a monograph by him.

Omega Portland Cement Co.,

Organized Feb. 18, 1899; capital, \$300,000; Jonesville, Hillsdale Co. The officers were: Frank M. Stewart, president; Israel Wickes, vice-president; Chas. F. Wade, secretary-treasurer; George H. Sharp, superintendent; Homer C. Lash, chemist.

The following report was prepared for us by W. M. Gregory, and was printed in the Michigan Miner for May 8, 1901, Vol. 3, No. 6.

The Omega Portland Cement Company, of Jonesville, Hillsdale County, Michigan, with a plant at Mosherville, owns extensive land tracts in Section 15, Township 5 south, 3 west. The plant stands near Cobb's Lake, on the Fort Wayne branch of the L. S. & M. S. Railway. This lake is one of a series of small lakes at

*See especially pages 175 to 190.

the headwater of the Kalamazoo River. In the near vicinity are Hastings, Johnson, and Mosher's Lakes, and many large areas of marsh. All by actual tests and explorations have been found rich in marl deposits of an excellent quality. The immediate topography of the land in this region is rolling and hilly, this being in the locality of parallel morainal ridges deposited by the ice fronts as it retreated to the north. The clay loam forms a storage basin for the lakes—three to four miles is the average distance from the crest to crest of the valley which holds this lake chain. The valley sides are gently sloping and in places covered with sand. This region of meandering creeks, sluggish rivers and plant choked lakes was formerly considered valueless and even hindered farming interests. The discovery of marl has been the means of making a busy little village in the midst of what was once worthless soil. This is only a type of what is occurring in many places in our State. Northeast of Jonesville there are many lakes of this same character. Already at Woodstock a 600 barrel plant has been erected, and a prospective plant is in consideration at Grass Lake. Near Hanover, Moscow, Duck Lake and Addison Lake are lands rich in marl deposits. At Coldwater, Quincy, Bronson, Union City and Sand Lake extensive deposits occur and four of these places have successful plants in operation. Spencer Lake, some miles east, has also a marl bed. This region within a radius of less than fifty miles is especially favorable for extensive cement manufacture because of the abundance of marl and clay. A few words concerning the lakes in this region: They are all elliptical in shape, and on the southern shore are low morainal ridges which extend northeast to north; in many cases partly enclosing the lake. A mile is the greatest length and one-half mile is the average width. The most valuable marl deposits occur in the deepest lakes, and in fact no extensive amount occurs in any of the shallow lakes, and in such cases the sand renders the marl valueless, as some of our manufacturers have found by experience. No large inlets are known to exist in lakes with an abundance of the deposit and as a rule the outlet is plant choked. The water is in the greatest part derived from the underlying Marshall sandstone.

The plant of the Omega Company has a daily capacity of 700 barrels. The buildings are of brick and steel, and the storage

house of cement concrete. The power house is 80x160 feet, containing a 750 horse-power engine, air compressors, pumps, dynamo, etc. The largest building or wet end department is 80x200 feet, and here the handling of marl and clay takes place. The marl is taken from the lake, which is 400 feet east of the mill, by a large steam dredge, and the beds of marl run to an average depth of 50 feet. The lake is one-half mile in length and one-quarter mile wide, being filled along the shore with much plant material. At the center of this lake a depth of 40 to 60 feet is found. For convenience in handling the marl the lake has been slightly lowered by dredging the outlet.

The slimy marl taken from the lake bottom by the dredge is deposited in horse cars, skips or buckets, with a capacity of one cubic yard, and drawn to the conveyor shed, 30x130 feet, where the marl is elevated and conveyed by trolley and by automatic dump in skips dropped into the stone separator, which disintegrates the marl and relieves it of all sticks, grass and stones. In this building the clay, which is shipped in from Millbury, Ohio, is pulverized by passing through a dry pan, dried and weighed, and elevated to the mixing floor, where with the marl coming from the stone separator is mixed with the clay, forming a mud or slurry and passes to the pug mills.

The Omega Company also have a clay bed one and one-half miles northeast of the works, which matches the clay brought from Millbury, and which they use at times when weather and roads will permit of transportation economically.

ANALYSIS OF MILLBURY CLAY.*

SiO ₂	64.85
Al ₂ O ₃	17.98
Fe ₂ O ₃	5.92
CaO	2.24
MgO	1.40
Volatile matter	4.98

It would seem quite possible that some of the shale outcrops near Reading, or south of Jackson, would furnish suitable clay. Clay taken from the surface, if free from sand, is more apt to

*Compare other analyses of this clay elsewhere given, e. g., those made by J. G. Dean at the Peninsular plant at Cement City, and those given by Prof I. C. Russell in his report in the 21st Annual of the United States Geological Survey.

prove satisfactory for cement manufacture, as it is easier to mine and freer from lime than a lower strata. The manufacturer wishes a clay low in lime.

Slurry is carefully watched and tested at the Omega plant, and no trouble has been encountered through presence of sand in the marl or clay. After leaving the disintegrating pug mills, the slurry passes into vats and is pumped up to an elevated tank, where it is again screened and runs by gravity to the mixing and grinding wet tube mills, these mills being lined with wood and one-half filled with Greenland flint pebbles. After the material has passed through these mills it will all pass a sieve of 10,000 meshes without residue. The object in very fine grinding is the attainment of the most intimate admixture possible of the clay and marl, so that the heat will quickly produce incipient vitrification. Slurry is then passed into large storage tanks and from these passes by gravity as needed into vats at rear of the five 60-ton rotary kilns; these are 60 feet long and six feet in diameter: the shell being made of extra heavy boiler iron, lined with aluminate brick. The slurry is pumped from vats and forced into the end of the rotary, the rotaries being set on an incline of one-half inch to the foot. The department containing the rotaries is 80' x 100'. The rotaries are heated to about 2,900° F. by means of a gas flame generated by a continuous blast of powdered coal; the slurry while in the kilns is subjected to temperatures varying from 1,290° F., at which CaO , SiO_2 is formed, to 3,000° F., where CaO , Al_2O_3 is formed. The calcined product of the kilns is termed clinker and has the following analysis:

SiO_2	22.24
Al_2O_3	7.26
Fe_2O_3	2.54
CaO	64.96
MgO	2.26
SO_3 .....	.41
H_2O and CO_2 .....	.33

The clinkers, if good, have a lava-like texture, being somewhat porous and with a greenish black bronzed color. Too much clay is shown by a tendency to give a flaky powder on cooling. An excess of lime gives a clinker of great hardness with a glassy black luster, or a fractured surface may show white specks of free lime. The excess of lime is very injurious to cement, because

caustic lime expands in slaking and will disintegrate the cement mortar and produce "blowing." Too much silica will cause the clinker to crumble. Iron imparts a bluish black color and tends to produce fusion in the presence of heat.

The building where the coal is prepared for use in the kilns is 52 ft. x 68 ft. in size, and contains a preliminary crusher, dryer, preliminary pulverizer and two German tube mills for finishing the product. The coal is pulverized to pass sieve of 10,000 meshes with not over two per cent residue. On an average three cars of coal are used per day and all is prepared in this special way for use and conveyed by blast from fans into the kilns. The composition of the coal is an important factor, as an abundance of sulphur or iron pyrites is a damage to the quality of the cement, and the percentage of ash in the coal is also an important factor, and coal must be analyzed each day.

PITTSBURG COAL.

Moisture	1.00
Vol. matter	39.37
Fixed car.	55.82
Ash	3.81
Sulphur .....	.92

The coal item in the expense of manufacture is a large one, and if Michigan coal could be used it might lessen the cost, but as yet its use has not been successful in this plant. After the clinkers are properly burned they pass from the rotaries to the cooling and grinding department.

The grinding mills are of the ball and tube mill patterns of German manufacture; the fine grinding of the clinker is one of the essential elements of cement manufacture. The following are some of the tests of the Omega brand:

THE OSBORN ENGINEERING CO. (INCORPORATED). CLEVELAND, OHIO. CEMENT TESTING DEPARTMENT.
Report No. 2. Records, p. 99. Reports of Tests of Omega Portland Cement. Samples received from John Laylin, City Engineer, Norwalk, Ohio.
Reported to John Laylin, Sept. 6th, 1900.
Fineness, Activity, Constancy of Volume.

Brand or Mark.	Fineness.		Rate of Set.		Result of Pat. Tests.		
	Per Cent Passing Sieve No. 80.	Per Cent Passing Sieve No. 100.	Initial Hrs. Min.	Final Hrs. Min.	Hot Test.	Cold Water.	Air.
Omega.....	99.8	99.5	2-10	4-10	O K Boiling Test O K	O K	O K

Tensile Strength in Pounds per Square Inch. Results given for Tests of Sets 3 of Briquettes.

Brand or Mark.	Proport's by weight.			Age, 24 Hours.			Age, 7 Days.		
	Cement.	Sand.	Per Cent of water.	Maximum.	Minimum.	Average.	Maximum.	Minimum.	Average.
Omega.....	1	3	22	354	322	361	683	550	601
".....			11	.....	.....	.....	339	263	298

We certify that the above tests were carefully made.
THE OSBORN ENGINEERING CO.
By BENJAMIN L. GREEN.

It is said that 98% will pass a sieve of 10,000 meshes to the square inch, and that briquettes possess a tensile strength of 400 to 700 pounds when one week old and 500 to 800 pounds when one month old.

In the season of 1900 it produced 54,500 barrels, in 1902, 120,000 barrels.

The following are three analyses by Mr. W. H. Hess from the Cement and Engineering News for February, 1900:

	1	2	3
Silica	39.53	58.24	68.21
Alumina	11.46	20.56	18.64
Iron oxide	4.59	5.68	5.32
Calcium oxide	13.78	0.61	0.22
Magnesium oxide	5.19	9.24	9.16
Sulphur anhydride	1.62	9.91	9.12
Difference, carbon dioxide, organic matter, water, etc.	23.83	15.49	7.33
	<u>100.00</u>	<u>100.74</u>	<u>100.00</u>

In No. 1, which is of the surface clay type, the calcium oxide would mean 24.63 per cent of the carbonate, and similarly 19.84 magnesium carbonate, or 35.47 carbonates, which would leave from the "difference" about 7.33 for organic matter, basic water, alkalis, etc.

Peninsular Portland Cement Co.

Organized June 24, 1899; capital, \$875,000. The office of the company is at Jackson, and Jackson capital is largely interested, but the plant is in the northwest corner of Lenawee County at Woodstock, on the L. S. & M. S. R. R., and Cement City on the Cincinnati Northern, the latter town site having been platted by the company. The officers were: W. R. Reynolds of Jackson, president; C. A. Newcomb of Detroit, vice-president; W. F. Cowham, secretary and manager; N. S. Potter of Jackson, treasurer.

The capitalization was half 7% preferred stock to be returned in 5 years. The net cost of manufacture was estimated at 80 cents.

The output when I visited it in the fall of 1901 was about 700 barrels a day. The following notes are from my visit and information kindly furnished by Mr. J. G. Dean, then chemist.:

The plant is located on the borders of Goose Lake not far from the northwest corner of Lenawee County.

The marl is dredged from the water of the lake, and forced through a pipe line into the marl tanks, where it is stirred and allowed to flow slowly into the mixers. While in transit the clay, which comes from Millbury, Ohio, is incorporated in the right proportions by an Archimedean screw. From the mixers it passes into the slurry tank, thence into the rotary roasters, in which a coal dust blast gives the heat. The coal is high in volatile matter and low in sulphur. At the lower end of the rotary it drops as a clinker and then passes into the grinder where it is reduced to powder, by being rattled with flint pebbles brought from abroad (France and Greenland). Experiments with Michigan pebbles have proven entirely unsatisfactory. The plant is producing about 700 bbls. a day with six kilns, and is beginning enlargement. The company owns a number of marl lakes in the region besides, but Goose Lake is the one which they are now using. It lies in an east and west deep trough, 60 feet or more, below the adjacent county. This trough to the east crosses the line of the Cincinnati Northern in a wide valley or open swamp, probably largely underlain by marl, and is said to extend up into Jackson County to the northeast. The outlet of the lake is to the west and the trough extends there also.

This trough appears to be not merely superficial, but to extend to the rock surface also, for in the village of Cement City half a mile north of the plant one has to put down a well but 8 to 11 feet to encounter sandstone and shale, while in the lake 60 feet below, soundings even 80 feet deep are said to be sometimes still in marl. Elk horns are said to have been found 30 feet down.

Not far north on Sec. 19, T. 4 N., R. 1 E., in a low swamp about the same distance below the high flat-topped hills as Goose Lake there is a drilled well (t. 50° F.) flowing. It is quite likely, therefore, that as seems often the case around marl lakes there is an upward artesian pressure of the ground water. It will be noticed that this lake conforms to Hale's rule that the marl lakes tend to lie in deep depressions.

The water is also hard, as is shown by the following analysis by Dr. Hodge:

	Grains per U. S. Gallon.	Parts per thousand.	
CaO	6.410	.110	.101CaO+.079CO ₂ =.186CaCO ₃
MgO	2.562	.044	+.048CO ₂ =.092MgCO ₃
Fe ₂ O ₃ Al ₂ O ₃	tr	tr	
SiO ₂ .....	.203	.003	
SO ₃ .....	.800	.014	+.009CaO=.025CaSO ₄
CO ₂	6.275	.107	
Alkalies etc. ....	.220	.004	
Residue	16.470	.282	

Now in this analysis it is noteworthy that after supposing that all SO₃ is combined with CaO and that the MgO is combined as carbonate, there is not enough CO₂ (.107—.048=.059 instead of .079) to satisfy the calcium oxide. This perhaps indicates some organic salt of lime, for instance the calcium succinate discovered by Davis.

Another point is that the water, as will be seen by reference to Treadwell & Reuter's paper, is almost or quite saturated with lime and magnesia. The sample was taken over the marl bed, directly at the mouth of the intake ditch.

A third point of interest is the higher ratio of MgO to CaO than in marl or clay. This indicates that the water is of a residual nature, left after the deposition of the marl. The company own a clay bank about two miles west of the plant, on the north side of the hollow in which the marl lies. They have not used it for cement manufacture, preferring to use Millbury Ohio clay of the composition of Analysis 1.

(Average of 50)

	1	2	3	4	5
SiO ₂	61.06	67.06	55.26	58.85	45.27
Al ₂ O ₃	18.10	20.50	23.34	18.36	8.33
Fe ₂ O ₃	6.65	2.52	2.52	7.16	4.84
CaO	1.29	.94	4.15	1.18	15.99
MgO .....	.53	tr.	tr.	1.98	
SO ₂	1.05	tr.	2.00	.38	
H ₂ O and organic matter	9.20	8.01	11.40	8.13	
Difference, alkalies, etc.	2.12	0.97	1.33	2.96	
	100.00			100.00	

Analyses 2 to 5 are of local clays,—No. 2 from under the marsh, No. 3 a surface yellow clay probably leached of much of its lime,—No. 4, also from the top of the bank, with a low per cent of lime, while No. 5 is a partial analysis of the clay 8 feet down in the bank. A similar relation of clay analyses is very widespread and will be noticed in many other sets given in this volume. From such analyses it is probable that the ground water leaches out the carbonates unequally, preferring the magnesia, and by comparison with the following marl analysis we see that the agent which throws down the marl decidedly prefers the lime, so that there must tend to be a concentration of the magnesia in the water:

ANALYSIS OF GOOSE LAKE MARL.

CaO	51.56
MgO	1.26
SiO ₂	0.22
Fe ₂ O ₃ , Al ₂ O ₃	0.76
Volatile matter, etc.	46.20
	100.00

The marl abounds in shells which have been determined by Mr. Bryant Walker in his paper elsewhere given, but Chara is also found in the marl. As bearing on the origin of the marl it is worth noting that at times streaks of material which dredgers would call sand or gravel are struck. This proves, however, to be pure calcium carbonate and is probably largely composed of the Schizothrix aggregates which are

elsewhere described. They tend, however, to settle in the slurry and cause trouble. The marl is said to range from 10 to 42 feet thick, and the lake is half a mile wide and a mile and a half long, the deposit of marl being over 300 acres. Besides this lake other lakes in the neighborhood are owned by the same company. It is said that the average of over 200 borings ran 96.12% CaCO_3 and less than 1% Mg.

Peerless Portland Cement Co.

Organized Aug. 23, 1896; capital, \$250,000. Oldest of the recent plants. First operated as a vertical kiln plant, as when visited by Hale and Ries, and when the view given in Plate III was taken; it has recently been remodelled to the rotary kiln.

The officers of the company are: A. W. Wright, of Alma, president; S. O. Bush, Battle Creek, vice president; J. R. Patterson, general manager; Wm. H. Hatch, secretary and treasurer; directors, the above officers, with W. T. Knowlton, Saginaw. It is a close corporation, and the stockholders are few.

The plant is located at Turtle Lake near Union City close to the line between Branch and Calhoun Counties.

Six hundred and seventy-five acres of marl land are owned by the company, and is reached by means of a little railroad. The marl is found upon the surface, and is so dry that water has to be added when it reaches the plant. The marl is almost entirely free from organic matter and is very readily worked. By means of a bucket dredge, operated on a track, the marl is dug and lifted into the dump cart.

To obtain the marl thus dry the level of Turtle Lake, "which had been twice lowered before, the last time in 1873," but still stood 22½ feet above the St. Joseph River, was lowered some 14 feet.

From the Detroit Journal of April 16, 1902, we cite the following account of the changes in the manufacturing plant:

"Intermittent vertical kilns were first installed by the company. These kilns were charged, then lighted and burned out like a lime-kiln. From a distance of three miles the marl was first hauled to the plant in wagons, then it was mixed with clay in a pug mill and made into bricks. These bricks were first dried in a drying kiln, then piled in the burning kilns with alternate layers of coke. After being burned the clinkers were drawn off and ground. The process was necessarily slow, as compared with that in use the present day. Two years ago another change was made in the mill and Dietch Continuous Vertical Kilns installed. In these kilns the mixture was charged at the top and the clinker drawn off at

the bottom. Still progressing the company decided last fall to construct a modern cement mill and to that end hundreds of workmen have been engaged all winter in the erection of a model cement plant. Many entirely new features have been introduced into this mill, and right from the start an output of 1,200 barrels per day is confidently expected from the eight 70-foot rotaries. Two hundred thousand dollars is being expended upon this plant.

"Beds of both plastic and clay shale owned by the company are located within a mile of the mills. The shales belong to the Cold-water formation.

"The cars of marl are pulled up an elevated tramway on the track scales where the marl is weighed, and then the clay is added before being dumped into the stone separator. From there it goes to the pug mill and then into a large tank where through return pipes the mass is kept running continuously in order to obtain a uniform mixture. It is corrected at this point by the addition of the proper amount of clay or marl determined by the chemist. From these tanks the mixture is pumped into the wet grinding tube mills and then falls into great floor tanks of concrete. In the bottom of these tanks a continuous screw conveyor forces the slurry into mammoth concrete correction tanks. These tanks are the source of just pride to the engineering force of the company. They are constructed entirely of concrete and are 22 feet deep by 22 feet wide and 22 feet long. The slurry in these tanks will be agitated by compressed air. The clay is prepared by being first dumped into a dryer and then ground in a Williams mill.

"The great rotary room is undoubtedly the most interesting part of the plant. Some innovations are here introduced that will materially increase the output of each rotary. The inventions are the product of advanced thought and the broadest of experiments. The rotaries are seventy feet long, being ten feet longer than the largest rotaries in any Michigan mill. The pulverized coal, to feed the rotaries, is prepared in a separate building where the most improved coal grinding machinery has been erected. The Peerless company has placed devices on the rotaries from which the waste heat from the kilns is utilized in drying the slurry before it enters the kilns. This is automatic and is said to increase the capacity of each kiln to a marked degree. The rotary room was constructed on a side hill and this has proven especially advantageous, as it saves the handling of the clinker as it leaves the kilns. Under the clinker end of the kilns has been constructed a retaining wall and in this room, 21 feet below the kilns, are the foundations for the eight automatic Wentz clinker coolers, which are being erected so that the hot clinker falls directly into them. By this device the hot air is fanned off of the clinker and driven back to aid in reducing more slurry to a calcined state.

"As the clinker drops from the coolers it is conveyed along the floor to the rolls and from there into eight Griffin mills and then into two large tube mills for the finishing process. As the cement leaves these mills it is elevated by belt and tripper arrangement to the top of the three-story warehouse and there dumped into hopper bins. These bins are two stories in height and are con-

structed of the best Kentucky oak, the huge pillars not depending upon the walls of the building, the construction being entirely within itself. As the cement drops from the third to the second story bins it is turned over and from there goes to the packer. The old and the new warehouses, which extend along the Michigan Central tracks, have a capacity of 100,000 barrels. It will be seen that the company is amply provided for winter storage. At the track, coal can be unloaded and elevated to the boiler room of the plant.

"The power plant promises to be one of the finest in the state. Four Scotch Marine internally fired boilers will furnish steam for driving a 500 horse-power Hamilton Corliss engine, a Fitchburg Tandem Compound 450 horse-power, and a 300 horse-power simple engine. Rope drives will be used in part of the plant. Twenty electric motors are being installed and electrical transmission used to advantage in driving the gear of many of the machines."

Bronson Portland Cement Co.

Organized March 3, 1897; capital, \$500,000. It is said that there is a mortgage of \$100,000 on the plant which is said to have cost about \$250,000. This is one of the well established plants of the State, and has been visited both by Dr. Ries* and Mr. Hale† and tests and a description of the process of manufacture are elsewhere given. In materials and location it is like and not far from those of the Wolverine Co.

The following are additional analyses of the Bronson clays, beside that given in Part I of this report.

REPORT OF ANALYSIS.

Date of receipt, Dec. 5th, 1900.

Composition	592 65	593 66	594 67	595 68
Silica	61.94	56.64	61.10	59.36
Alumina	11.58	12.18	13.91	12.38
Iron oxide (ferric)	3.49	3.59	3.62	3.62
Oxide of calcium	5.92	8.17	6.32	5.63
Oxide of magnesium	4.85	4.29	3.91	4.62
Sulphuric acid (anhydrid) .....	.18	.31	.31	.30
Organic matter				

Respectfully submitted,

(Signed) W. H. SIMMONS.

Bronson, Mich., Dec. 17th, 1900.

*This volume (VIII), Part I, pp. 42 and 43.
†Chap. VI, p. 104.

Newaygo Portland Cement Co. (Gibraltar Brand.)

Capital, \$2,000,000; organized May 24, 1899. Cornerstone laid June 29, started June 5, 1901.

The officers of the Newaygo Portland Cement Company are Daniel McCool, member of American Society of Civil Engineers, president; Wm. Wright, vice president; B. T. Becker, secretary and treasurer. Directors: F. G. Bigelow, Milwaukee; H. D. Higginbotham, Chicago; George Barrie, Philadelphia, and W. Northrup, St. Louis; Clay H. Hollister, Grand Rapids, Mich.

Description by Richard L. Humphrey.*

The Newaygo Portland Cement Company's plant is located at Newaygo, on the banks of the Muskegon river, thirty-six miles north of Grand Rapids, Michigan. It is one of the finest designed and equipped plants in the State of Michigan.

The plant is electrically operated, the power being furnished by two 500 H. P. 3-phase generators, driven by eight Lombard water wheels acting under a 15-foot head.

The water is furnished by the Muskegon river. The accompanying views, Plates XII and XVIII, show the dam, race way and interior of power house.

The slurry is agitated and handled entirely by compressed air. The efficiency of this system cannot be overestimated. The centrifugal pumps usually in use are very expensive to maintain as they wear out very rapidly.

The absence of line shafting is noticeable, each machine being equipped with an individual motor, in some cases two, which enables the mill to continue in service in case of break down of one of the motors. The automatic system for controlling the compressed air is admirable.

The marl is found in a series of lakes owned by the company in Newaygo county and about five miles from the plant, known as Little Marl, Great Marl, Pickerel, Kimball, Fremont and Hess lakes.

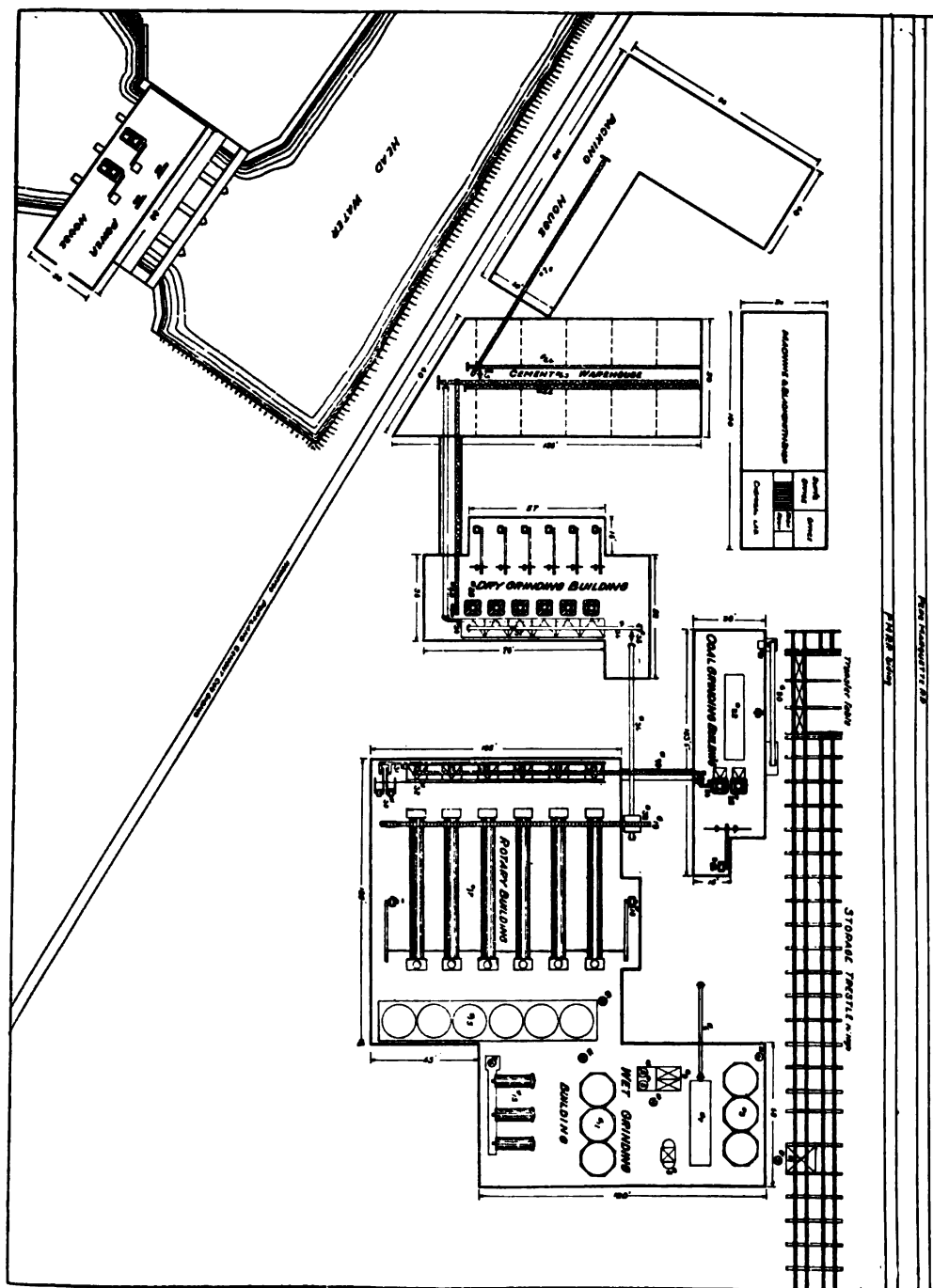
The following is an analysis of marl taken from the Great Marl lake:

Silica	1.24
Iron and Alumina .....	.80
Calcium carbonate	90.90
Magnesium carbonate	2.97
Organic matter by difference.....	4.09
	<hr/>
	100.00

*Consulting Engineer, Philadelphia, Pa.



GENERAL VIEW OF PLANT.



PLAN OF NEWAYGO PLANT.

1





DAM AND RACE-WAY FOR NEWAYGO PLANT.

1

2

The composition of the marl in calcium carbonate ranges from 65 to 95 per cent.

Clay is found on the company's property along the Muskegon river opposite the plant; the following is a representative analysis of this clay:*

Silica	55.84
Iron oxide	3.02
Alumina	8.90
Lime	9.98
Magnesia	5.16
Loss	13.68
	<hr/>
	96.58

The cement produced by this plant is first-class in every particular, and the machinery is the best of its kind.

The following is a brief description of the plant:

The mill is on the line of the Pere Marquette railroad over which road for a mile and one-quarter the marl is hauled to the mill; the remaining three and one-half miles is over the cement company's siding.

The dredge and plant used in excavating the marl is shown on Plate XXII.

The marl is dumped into a bin [(1) on Plate XVII]. There is also storage provided, under the trestle (400 feet long), to supply the mill during the winter months.

From the bin the marl flows through a gate in the bottom, operated by a slide valve, into a machine called a separator, which drives the marl out through a perforated head in the machine, separating from the marl all foreign matter, such as sticks, stones, etc. Water is introduced at this point in quantity (about 55%) sufficient to reduce it to a slurry.

The pure marl flows through a pipe into pump (2) which pumps it by compressed air into three storage tanks (3) connected together by pipe. These tanks hold about 90 cubic yards each. From these tanks the chemist takes his samples for analysis, to determine the proportion of clay to be added. From the tanks the material, now in form of slurry, flows by gravity in a pump marked (4) which pumps it into two measuring tanks (5), these being used alternately. The

*At present, however, the company is using a clay found in connection with the gypsum at Grand Rapids whose analysis is more like that given in Part I, pp. 40 and 41. L.

clay is brought from storage and fed into a pair of rolls, then into a pug mill where water is added and it is reduced to a thin slurry. From this mill it passes into two Gates' tube mills in which it is made impalpably fine. This in turn is forced or pumped by air into a measuring tank.

The marl and clay are fed separately from the bottom of the measuring bins into a measuring hopper.

From this hopper it is pumped into three 90 cubic yard tanks (11).

The number of hoppers of marl and clay pumped into each of these tanks will depend on the composition of the marl. When the tank is full it is thoroughly agitated by air. The chemist then takes another sample. These are called correction tanks. Should the composition not be correct clay or marl is added until the desired mixture is obtained.

From these tanks the slurry or syrupy mixture of clay and marl flows by gravity into a pump (12) which forces it into the automatic feeders into the three tube mills (13), in which the material is reduced to an impalpably fine state. The tube mills discharge it into a trough running to a pump (14), which forces it into the 90 cubic yard tanks (15) back of the kilns; there being a tank for each kiln. All tanks are continuously agitated by means of compressed air.

From the tanks it is pumped into automatic feeders from which it is fed into the rotary kilns marked (17), in which it is clinkered and is discharged into the McCasslin conveyor marked (19), which forms a continuous belt around all the rotary kilns passing in a trench underneath, then up a tower at the side of the building, overhead through the ventilator or louvre of the building and down the opposite side, where it is discharged into a cooling tower (33), and delivered by this tower onto a conveyor belt (34), which takes it to the dry grinding building and delivers it to elevator (35), by which it is elevated and deposited on conveyor belt (36) which in turn delivers it to clinker storage bins marked (37), there being one for each Griffin mill. From these bins it is fed by gravity into the Griffin mills marked (38) and pulverized to an impalpable powder; flowing from them by gravity again into a screw conveyor marked (39), by which it is delivered to elevator (40), and delivered by this elevator to either screw conveyor (41) or belt conveyor (42), either one being in reserve in case of a break down. These conveyors take the finished cement and deposit it again into a screw conveyor (43).

which carries it overhead, through the cement warehouse, emptying it into any bin desired.

When the cement is shipped, it is drawn from the bottom of any one of these bins into screw conveyor (44) of which there are two, one on either side of the alleyway, conveyed by the screw conveyor to a second screw conveyor (46), which delivers it into the packing bins in the packing house, where it is either barreled or sacked by machinery, and if cars are not at hand to take it to market, it is piled in the warehouse adjoining the packing house.

The coal is either shoveled direct from a car standing on the trestle onto the conveyor belt (20), or is wheeled from storage under the trestle and dumped onto this same belt, which carries it to a coal cracker (21). From there it is elevated into a Cumber dryer (22), passes from the Cumber dryer into a second elevator, which carries it up and dumps into small bins over Griffin mills (23), where it is pulverized and then passed by a screw conveyor (26) into elevator (27), which elevates it into screw conveyor (28), by which it is carried and deposited in coal storage bins (29). From there it is fed into the rotaries by a blast of air from fan (31), driven by motor (30). These rotaries are all driven by motor (18) of which there is a duplicate kept in reserve.

In the coal grinding building the machinery is driven by motor (25), belted to a jack shaft (24), which drives both the Griffin mills. Each of the Griffin mills in the dry grinding building is driven by a separate motor, as in each of the tube mills in the wet grinding building. The agitators of each set of tanks, Nos. 3, 11 and 15, are also driven by separate motors.

The plant has been in continuous service for over one year during which time it has proved to be one of the most successful and economical in the State.

The story of the discovery of the deposits of marl is as follows:*

"A year ago Charles E. Greening, of the firm of Greening Bros., extensive nurserymen at Monroe, was on a business trip through the northern part of the lower peninsula. On May 23 he delivered an address at Newaygo, and the day following joined a fishing party at Pickerel Lake, near that village. While sitting on the trunk of a fallen tree, Mr. Greening observed that the roots of the tree were covered with a white substance resembling snow. His curiosity prompted him to taste it and he detected in it a strong flavor of lime. He sent a sample to the Agricultural College for analysis, but never heard from it.

*Grand Rapids Herald, May 9, 1899.

"A few months later Mr. Greening met Prof. Fred H. Borradaile, State analyst, and gave him a sample for analysis. When the latter reported he startled Mr. Greening by urging him to go to Newaygo at once and buy up all the land containing the deposit that he could get his hands on, explaining that the substance was a most valuable specimen of marl.

"Mr. Greening hastened to Newaygo and immediately purchased about 1,000 acres of land surrounding four little lakes, the shores and bottoms of which contain unlimited deposits of marl which is said to be of a finer quality than any heretofore discovered in this country, the analysis showing 96 per cent of carbonate of lime, with little or no trace of iron. Within a short distance of the marl beds there is to be had an abundance of clay, which is an essential in the manufacture of cement.

Numerous other deposits of marl at Pine Lake, Fremont Lake, etc., exist not far off, elsewhere referred to. That of Fremont Lake is described by Mr. Hale on p. 135.

Elk Rapids Portland Cement Co.

Organized March 3, 1900; capital, \$400,000. Bonds issued in 1902 to improve machinery, etc., \$100,000. Original actual cost of plant about \$225,000, the balance of stock being issued for land or unsold and issued as bonus with bonds, which were floated at par.

Officers: Schuyler S. Olds, president and general manager; Fitch R. Williams, vice president; Frank B. Moore, secretary and treasurer. Directors: Fitch R. Williams, attorney, Elk Rapids; M. B. Lang, merchant, Elk Rapids; Frank B. Moore, president Elk Rapids Savings Bank; Schuyler S. Olds, railroad counsel, Lansing, Mich.; Thomas A. Wilson, attorney, Jackson, Mich.; C. A. Whyland, Chicago, Ill.; H. B. Lewis, manager Elk Rapids Iron Co.

Within the limits of the village of Elk Rapids the plant of the Elk Rapids Portland Cement Co. has been erected. The company own a frontage of 80 rods on the shores of Grand Traverse bay, Sec. 20, T. 9 N., R. 9 W., and the plant was built at the water's edge. The surroundings are far more picturesque than usually found accompanying a large industrial institution. In a grove of pine trees the various buildings were erected, and thrusting its arm out into the waters of the bay, a distance of 1,200 feet, is a substantial pier. At the end 16 feet of water is found, which allows the largest boats on the lakes to discharge and load. This dock is equipped with clam shell, hoisting engine, boiler, etc., and the cable dock car system for loading and conveying cargoes to and from the plant. As lake transportation is generally cheaper than rail, the company possess a decided advantage in this particular. Tracks of the Pere Marquette also run to the mills and the company uses both methods of transportation.

Thirteen and one-half acres comprise the land owned by the company, upon which the plant has been erected. Two and one-

half miles south of the plant site, in the extreme northern end of Grand Traverse county, is situated the marl lands of the company. This tract comprises 350 acres of solid marl. It was formerly a shallow lake (Petobago Lake, sometimes called Tobacco Lake, Sections 5 and 8, T. 28 N., R. 9 W.), about 20 feet above Grand Traverse Bay, but the company drained off the water and the marl is now very easy to raise and put into the dump cars of the company. This great body of marl averages, in depth, throughout its extent about 18 feet. Very little muck or organic matter lies on top of this marl bed and it goes to the mill in a very pure state. They have also recently bought some limestone lands. Within a stone's throw of the plant, clay of fine quality has been discovered. Besides this clay the company own a fine bed of shale clay (Antrim shale) on the east half of Sec. 3, T. 33 N., R. 7 W., on Pine Lake in Charlevoix County, also I am told in Lake Susan, Charlevoix County, and if needed the Watervale lands, No. 23, could be acquired.

"The buildings of the company are quite extensive and are arranged with the view of economically handling the materials as they pass from one process to another. The buildings comprise, frame coal storage building with cement floors, 50x175 feet, equipped with coal crushers, two elevators, two screw conveyors, rope drives. Concrete storage and packing buildings, 98x118 feet, concrete floors and conveyors for handling the cement. The capacity of this building is about 30,000 barrels of cement. Machine and blacksmith shop of brick, 30x50 feet; this room is very essential in a cement plant as all necessary repairs can be made in a short space of time. This shop is equipped with all of the tools and machines necessary to perform a high class of work.

"The engine and grinding rooms are in one building. This is of brick, 80x160 feet, with steel trusses, iron roof and cement floors. Steam for power is generated in two Sterling water tube boilers of 500 horse power and the motive power consists of a 500 horse-power Russel engine, with rope drives, also a Westinghouse dynamo and engine for the lighting plant. These are separated from the clinker room by thick walls. Four Griffin mills are required to grind the clinker and in this room are clinker car conveyors, cement conveyors and elevators.

The rotary building is of brick set in cement and is 80x200 feet, with steel trusses, iron roofs, and cement floors. Here are found two pug mills, four tube mills, clay grinder, six large cement vats, ten steel slurry storage tanks, 12x16 feet each, and five Bonnet steel rotary kilns, 6x60 feet, lined with fire brick for burning cement clinker. The foundations of all machinery and all ground vats are constructed of solid concrete, resting on clay strata about eight feet below the surface of the ground. Besides these build-





DAM AND RACE-WAY FOR NEWAYGO PLANT.

any of them to correct the chemical composition. After being analyzed and corrected if necessary, the material is pumped to steel storage tanks located in the second story. Agitators keep the slurry in motion in all pits until pumped into the rotary kilns. The material is fed to the kilns through water-jacketed chutes with pulverized coal; all three kilns discharge into a concrete pit, from which it is elevated to the cooling towers.

Air is forced in at the bottom of these steel cooling towers, 12 feet in diameter and 22 feet high, arranged with a succession of metal floors, having radial openings, through which the clinker is swept by a scraper fitted to a central shaft. The clinker is moved 350 degrees on each floor, before falling to the next. Arriving at the bottom it is elevated into steel bins over the ball mills, from where it is raised and conveyed to bins over tube mills which finish the cement.

From here the cement is elevated and conveyed by an overhead conveyor, through the mill room wall, into the stock house, and discharged into two lines of conveyors resting on the top of the storage bins, thus delivering into any bin desired. These bins have hoppers bottoms and are arranged in two rows with a passageway between containing two lines of screw conveyors; these carry the cement drawn from the bins to an elevator at the packing room, which discharges it into the bins supplying the packing machinery.

The power plant consists of one 600 H. P. tandem compound condensing engine, and three water tube boilers. The river water passes from jet condensers to hot well from which feed water for the boilers is taken.

The engine is belted directly to the main line shaft which passes through the engine room walls in stuffing boxes, thus cutting out the dust from the mill; the engine room projecting beyond the walls of the mill so as to give clearance for main shaft. The shafting is so arranged that the power can be cut out from any department by the use of clutch couplings.

A notable feature of the plant is the relatively small area covered by the buildings when compared with the total capacity, making it one of the most complete plants in operation. Including the stock house with a capacity of 40,000 barrels, all the buildings cover an area of only 25,000 square feet, and the plant has a daily average of 450 barrels.

The above plants are those which were actually in operation in 1901. We take up next proposed mills which will in all probability be running before this report is out. The most extensive in plans will be the Hecla, which will be a group of allied industries, more like the Michigan Alkali Company last mentioned. The remaining three are Portland cement propositions pure and simple.

Hecla Cement and Coal Co.

Organized April 6, 1901. Capital \$5,000,000, in shares of \$100. A West Virginia corporation, but with offices in Detroit and business centering around Bay City, consisting of marl lands in Ogemaw county, and coal and clay shale lands in Bay county.

The officers and directors of the company are: Julius Stroh, president; Cameron Currie, first vice president; Waldo Avery, second vice president; Edward H. Parker, treasurer; U. R. Loranger, secretary; Lem W. Bowen, Theodore D. Buhl, James N. Wright, M. M. Green.

Briefly the plans of the company can be outlined as follows: The manufacture of Portland cement from dry marl and clay shale; the mining of coal, of which the lump will be marketed and the slack used in the manufacture of cement and the creation of power to run the great mills; the evaporation of salt in large quantities with the exhaust steam and hot gases escaping from the rotaries; the by-products of salt and limestone to be used in the running of a large chemical plant; the erection of coke ovens, also used as an auxiliary to the plants; the operation of a standard gauge railroad to be utilized for hauling the coal to the dock of the company for lake shipment as well as the raw materials to the cement plant.

The novel features of their plans are,—the transportation of the marl to the clay and shipping point, instead of building the factory at the marl bed; the use of waste coal and slack, and especially of Michigan coal, as well as clay and marl; the utilization of by-products and waste heat, and the employment of a dry process. Ordinarily the marl being the most bulky raw material, does not pay to ship. In this case, however, we have to counterbalance it a saving on shipping coal, clay and cement, while the marl comes down grade.

In the planning of the plant, marl analyses have been made by R. E. Doolittle, State Analyst, Lathbury and Spackman, and others. To the courtesy of U. R. Loranger we owe details of the company's analyses which cover a range of materials and have a scientific value in showing how analyses of such material run in the State. We append extracts from the reports of some of their experts. Beside the draining of the lakes and handling of the marl or boglime dry,* another important feature of this plant is the proposed utilization of shales of the coal measures.

*Edwards Lake has been lowered.

One mile of river front on the Saginaw river, near the mouth, and only a short distance below West Bay City, is owned by the Hecla company, where the cement plant has been erected. The erection of this plant will shortly be followed by the other mills included in the general plan of development.

The company owns about 6,000 acres of coal lands, about 800 acres of marl land, 2,000 acres of lime rock, and a mill site with nearly a mile of river front on the mouth of the Saginaw river, and is incorporated to manufacture and sell Portland cement, alkali, salt, paving and fire brick, coal, fire clay, etc. Experts who have looked over the property say that by reason of the fuel situation, with coal deposits under the company's mill site, it will possess a great advantage over those who are obliged to buy their coal in the open market and pay freight on it. The company will sell the lump coal and use its slack coal.

The four marl lakes, known as George, Edwards, Chapman and Plummer, are located on the headwaters of the Tittabawassee River, and all within the radius of five miles in the township of Edwards, Ogemaw county, Michigan, Plummer being on the Hampton branch of the M. C. R. R., and the others lying two, three and four miles respectively, from the same. There is a roadbed already constructed and in very fair condition, extending from Plummer Lake to Edwards Lake.

Your next deposit, known as Crapo Lake, lies a little less than two and one-half miles northeasterly from the village of West Branch, on the Michigan Central railroad, in Ogemaw county, Michigan, and about six miles north of George Lake.

Your Mills Lake deposit is located about four and one-half miles from the village of Prescott, on the Prescott branch of the Detroit & Mackinac railway, in Mills township, Ogemaw county.

George Lake.

The property at George Lake was found to consist of 380 acres, of which 200 acres are covered with marl. The marl is high quality, as shown by the following analysis, which is an average of samples taken from borings over the entire lake. Lab. No. 662 (see p. 260).

The chemical composition of the clay is shown by two average samples taken from the deposits as follows:*

Lab. No. 712 (see p. 266). Lab. No. 713 (see p. 266).

This lake presents probably the deepest deposit of marl of any owned by you, many borings showing a depth of from 27 to 34 feet, but the dry marl is thickly covered with a growth of small trees and brushwood, and a large portion of the deepest marl is

*It will be noticed that these and all the other clays which are surface clays in connection with the marl deposits are about one-fourth to one-fifth carbonates, with generally 5% MgO. The company is depending not on these, but on shale clays of the coal measures.

under water of considerable depth. The water in this lake could, however, be reduced by deepening the channel at the outlet, but it is a question whether a sufficient change of water level could be made without an expenditure of a considerable sum of money.

Edwards Lake.

Edwards Lake lies in a southwesterly direction from George Lake and is about three miles distant. It contains the largest acreage of marl of any of your deposits. The land owned by you here aggregates about 400 acres, of which 240 acres are covered with marl, of an average depth of 20 feet. The lands of this property are situated in sections 21, 22 and 27, and a second body is located about one mile eastward on the stream formed by the outlet. The clay deposits immediately at the outlet of the lake extends under the surface, and has been found by careful examination to cover a tract one-half mile square, and is of good depth, though overlaid to some extent with sand and gravel. A second deposit further down the creek has been explored for about 40 acres, and shows a depth of 20 feet, at which point the bottom was not reached.

The analyses of these two clays are as follows:

Lab. No. 658 Edwards Lake, No. 1 (see p. 266).

Lab. No. 676. Edwards Lake, No. 2 (see p. 266).

The marls are also of most excellent quality, as shown by the following analysis, which represents an average of some thirty samples taken in various parts of the lake.

Lab. No. 659. Edwards Lake Marl (see p. 260).

Chapman Lake.

Chapman Lake is in the extreme southwest corner of Edwards township, sections 31 and 32. The property owned by you here consists of some 230 acres, of which 160 are marl. Chapman Lake is fully equal in the quality of the marl to the preceding lakes, and partakes equally with Edwards Lake in the advantages resulting from being readily drained.

An average analysis of Chapman Lake is as follows:

Lab. No. 663. Chapman Lake Marl (see p. 260).

The clay deposits examined in connection with this lake are located in section 7, Clement township, Gladwin county, about three miles distant from the lake. The bed is over 40 feet thick, and has been explored for a distance of over one-half a mile.

An average analysis of this clay is as follows:

Lab. No. 660. (Sec. 7, see p. 266).

Another clay deposit in section 3, same township and county was examined, an average analysis of which is as follows:

Lab. No. 661. (Sec. 3, see p. 266).

Plummer Lake.

Plummer Lake is the smallest of the group, but is advantageously located with regard to railroad transportation. The Hauptman branch of the Michigan Central railroad passes through your property at this point. The lake is situated about seven miles west from the main line of the Michigan Central railroad. At this point the property owned by you comprises some 120 acres of land, of which about 40 acres are marl, which is of exceptional purity, and only a small portion of it covered with water. The clay on this deposit lies in direct conjunction with the marl at the east end of the lake, and runs down under the marl at the southern side. The clay deposit is covered with about three feet of surface earth and is 40 acres in extent. The clay average is eight feet in depth.

An average sample of the marl shows the following analysis:

Lab. No. 623. Plummer Lake marl (see p. 260).

The analysis of the clay shows the best chemical composition for the manufacture of cement of any deposits examined in connection with the marl deposits, and is as follows:

Lab. No. 675. Plummer Lake clay (see p. 266).*

Crapo Lake.

Crapo Lake is located on the east side of the main line of the Michigan Central railroad, about two miles northeast of the village of West Branch in West Branch township, sections 7, 8 and 16. The property comprises 340 acres, of which about 240 acres are marl. This deposit has an average depth of about 12 feet, and is covered with a light growth of grass and brushwood, with a top coat of muck six inches deep. The brushwood can very readily be burned off, while the level of the lake can no doubt be lowered considerably by deepening the channel at the creek outlet, and thereby exposing nearly all the deposit. About two-thirds of this body of marl occurs in the low swampy basin which was formerly covered with water. At the present time several narrow channels pass through the deposit with here and there a small lake, all of which drains into the west branch of the Rifle River.

The marl in the small lakes shows a depth of at least 15 feet, while the water ranges in depth from two to fifteen feet. This deposit is entirely free from grit; analysis of samples shows it to be of uniform quality and containing a high percentage of carbonate of lime. Average analyses of samples taken from this lake give the following results:

Lab. No. 891. Crapo Lake marl, No. 1 (see p. 260).

Lab. No. 896. Crapo Lake marl, No. 2 (see p. 260).

*See, as regards the availability of surface clays, pp. 267 and 268.

The clay lands of the deposit are located along the bank of the lake, in sections 9 and 16, and cover about 40 acres, while the depth is about 30 feet.

Analyses of samples of these clays give the following results:

Lab. No. 822. Section 9 (see p. 265).

Lab. No. 823. Average of section 10.

Mills Lake.

Mills Lake deposit, located in Mills township, in sections 24 and 25, on the east side of the main line of the Michigan Central railroad, and about four miles from Prescott on the D. & M. railroad. This property covering 360 acres of land contains about 160 acres of marl. The main body of marl occurs in the lake under water, whose depth ranges from three to fifteen feet. The marl itself, has an average depth in the lakes of about 20 feet. At the north end of the lake a considerable part of the deposit of the marl is covered by water whose depth does not exceed three feet, and the entire lake level can be readily lowered by deepening the creek, and removing the log obstructions at the outlet. This will expose about three-fourths of the deposit. The marl in the lake is very uniform in quality, but in several spots is covered with a slight growth of vegetable matter; below this, however, the marl is of very great purity, having no topping or muck.

An average analysis of samples taken from this gives the following results:

Lab. No. 895. Mills Lake marl, No. 4 (see p. 260).

The clay deposits in connection with this lake are located about one-half mile below the lake outlet, bordering both sides of the creek draining same and covering about 80 acres. It is over 30 feet in thickness, and an average analysis gives the following results:

Lab. No. 904. Clay marked No. —04 (see p. 263).

Lab. No. 905. Clay marked No. 2 —05.

Samples of shale were taken from borings in four different locations on your coal field which show an extensive acreage, running from five to fifty feet. The analyses of four samples of these shales are as follows:

Lab. No. 727. Light shale (see p. 265).

Lab. No. 728. Dark shale (see p. 265).

Lab. No. 863. Goetz shale, No. 1 (see p. 265).

Lab. No. 906. Clay marked 06 (see p. 263).

These shales are all suitable for combining directly with your marl in the manufacture of the Portland cement; Lab. No. 727 and Lab. No. 906, being especially good.

The coal properties are taken up and discussed in detail by the report of Mr. Brown, superintendent of the N. A. Chemical Company's coal mines, and the report of Lippencott & McNeil, mining engineers.

The raw material after being mixed, ground and burned in a set kiln, was ground, and the cement showed the following results:

Lab. No. 921.

Silica (SiO_2).....	19.71%
Alumina and iron oxide ($\text{Al}_2\text{O}_3\text{—Fe}_2\text{O}_3$).....	11.03
Lime CaO.....	64.25
Magnesia (MgO).....	2.20
Sulphuric acid (SO_3).....	1.42

The marl was taken from your property at West Branch, and the shale from your property at Bay City.

In addition to the above analysis the finished cement was subjected to physical tests with the following results:

CEMENT TEST.

Fineness.

No. 100 sieve.....99.01%
No. 200 sieve.....84.70%

Cold Water Test Good.

Hot Water Test Good.

Setting Test.

Initial set 1 hr. 40 min.
Final set 6 hrs. 15 min.

Tensile Tests.

Neat 48 Hours.

Briquette No. 14,870 257 lbs.
Briquette 1 235 lbs.
Briquette 2 225 lbs.

Average 239 lbs.

CEMENT TEST.—*Continued.*

7 Days.

<i>Neat.</i>		<i>3 to 1.</i>	
Briquette No. 14,880	585 lbs.	Briquette No. 14,885	190 lbs.
Briquette	1 675 lbs.	Briquette	6 155 lbs.
Briquette	2 520 lbs.	Briquette	7 140 lbs.
Briquette	3 640 lbs.	Briquette	8 225 lbs.
Briquette	4 675 lbs.		
<hr/>		<hr/>	
Average		Average	177 lbs.
619 lbs.			

28 Days.

<i>Neat.</i>		<i>3 to 1.</i>	
Briquette No. 14,890	780 lbs.	Briquette No. 14,895	236 lbs.
Briquette	1 742 lbs.	Briquette	6 270 lbs.
Briquette	2 755 lbs.	Briquette	7 242 lbs.
<hr/>		<hr/>	
Average		Average	249 lbs.
759 lbs.			

Respectfully submitted,

(Signed) LATHBURY & SPACKMAN.

The following extensive suites of boglime analyses, which we owe to Mr. U. R. Loranger, are of especial value, as not select, but showing much better how an average deposit runs, than select analyses which are published in prospectuses. In regard to these analyses, however, as to many others, it must be remarked that probably what was directly determined was: calcium; magnesium; residue insoluble in HCl, which is called sand and clay, or silica; iron oxide and aluminum oxide precipitated together; and sulphuric anhydride. The calcium and magnesium are estimated as carbonates, and the difference between the total then and 100 per cent is called organic matter. But direct determination of the carbon dioxide shows as we have elsewhere mentioned, that it falls short of the amount calculated as sufficient to turn the calcium and magnesium into oxides by some two per cent. This is due to the fact that part of the calcium is combined with the sulphuric anhydride, and somewhat more with an organic acid (succinic acid). In practice, however, the calcium succinate would probably be soon broken up on heating into calcium carbonate and organic matter, so that it does not make much practical difference.

BOGLIME ANALYSES BY R. E. DOOLITTLE.

Sample No.	1	2	3	4	6	8	x	8 ft	9	E
Calcium as Carbonate.....	84.45	83.42	77.70	90.64	91.14	92.50	88.61	90.69	91.31	87.39
Magnesium as carbonate.....	2.76	2.08	3.43	2.30	2.62	0.39	2.25	1.56	0.34	1.22
Sand and clay (insol.).....	7.37	7.89	14.25	2.04	2.25	1.01	5.33	3.87	1.63	4.99
Iron and aluminum oxide.....	0.82	1.69	1.13	0.64	0.95	0.90	0.58	0.36	1.00	0.92
Sulphuric anhydride.....	0.60	0.83	0.48	0.47	1.00	1.97	0.45	0.43	1.91	1.70
Difference (organic).....	4.00	4.14	3.01	3.91	2.04	3.23	2.78	3.07	3.81	3.78
Totals.....	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00

Sample No. or mark.	Chapman.	Dunham.	No. 10	No. 12	No. 20	No. 19	No. 21	Campbell Lake E. Side.	Frost Dam.	Plummer Lake.
Calcium as carbonate.....	89.86	85.17	86.95	90.01	89.44	89.92	89.66	87.24	63.14	87.25
Magnesium carbonate.....	0.54	1.02	0.80	2.78	0.82	0.80	2.18	3.56	3.08	1.57
Silica.....	3.45	7.66	4.17	1.25	2.36	3.50	3.16	3.46	18.98	3.54
Alumina.....	1.46	1.38	1.76	0.44	0.54	0.72	0.44	0.80	6.23	1.94
Iron oxide.....	0.30	0.32	0.40	0.36	0.34	0.30	0.42	0.40	3.14	1.08
Sulphur anhydride.....	1.78	2.34	3.52	2.08	2.98	2.22	1.92	2.30	1.76	2.35
Organic matter by difference..	2.61	2.11	2.40	3.08	3.52	2.54	2.22	2.24	3.06	2.36
Totals.....	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00

Sample No.

- 1 is from Edwards Lake, T. 21 N., R. 1 E., 11 feet thick.
- 2 is from Edwards Lake, "a little high in clay."
- 3 is from Edwards Lake, "very high in clay with some sand, not a good sample."
- 4 is from Plummer Lake, "a very good sample."
- 5 is from Plummer Lake, "fair; rather high in sulphuric acid."
- 8 is from Plummer Lake, "fair; rather high in sulphuric acid."
- X is from Plummer Lake, "a good, fair sample."
- 8 feet, Chapman Lake, "a very good sample."
- 9 Chapman Lake, "fairly good marl though a little high in sulphuric acid."
- E. Chapman Lake, "good, fair sample, a little high in sulphuric acid."

On the whole, the above set of analyses run high in silica for bog-limes, and especially in sulphur anhydride,—gypsum.

The first analysis of the second set comes from Chapman Lake, like No. 9, of the previous set.

The next comes from Dunham Lake, Sec. 19, T. 21 N., R. 1 E.

No. 10 comes from Campbell Lake in the same township.

Nos. 12, 20, 19, 21, and the rest of this set are all from this township.

All the above samples were analyzed by R. E. Doolittle, State Analyst, and as regards the amount of sulphuric anhydride, which is high, it will be noticed that the lakes are in a region just south of that where the Michigan series is bedrock, in which gypsum occurs frequently in the drift. Some of the limes highest in sulphates are not high in iron, and the sulphates are probably not largely derived from pyrite. Silica is also often high. Of the sample at the First Dam, 18.93% is soluble silica and fine sand, 6.28% coarser sand.

Calcium as carbonate....	80.89	80.78	85.46	97.09
Magnesium as carbonate.	0.43	3.20	3.74	1.44
Silica	7.96	7.96	3.74	0
Alumina	3.74	1.76	1.88	
Iron oxide.....	0.62	1.16	0.40	trace
Sulphur anhydride	1.94	2.51	1.28	0
Organic matter by difference	4.42	2.63	3.50	1.47
Totals, 100.00.				

Of the set above, the first is from Plummer Lake, the second is also ("A"). The third is from Campbell's Lake, west side; the fourth from Plummer Lake, and all are by R. E. Doolittle. The first three have too much sand for cement,—better analyses are to be found in the other sets. There is more iron in the marls with sand and clay. In the pure boglimes it is only a fraction of a per cent.

BOGLIME ANALYSES BY LATHBURY AND SPACKMAN.

Sample No.	662	659	663	623	891	896	802	803	804	806
Calcium oxide..	58.28	51.44	50.83	52.38	49.45	50.75	48.74	49.47	49.37	50.43
Magnesium oxide.	1.22	1.23	0.89	1.49	1.33	1.46	1.46	1.44	1.23	1.38
Loss on ignition	46.34	43.32	45.05	44.31	46.06	45.02	46.51	47.30	47.29	47.08
Calcium as carbonate.....	93.35	91.85	90.76	93.53	88.30	90.62	87.04	88.24	88.16	90.05
Magnesium as carbonate.....	2.56	2.59	1.86	3.13	2.78	3.06	3.05	3.01	2.68	2.64
Organic matter, (loss on ignition less CO ₂).....	3.93	1.56	4.15	1.52	5.76	3.55	6.02	6.87	7.10	6.68
Silica.....	0.72	2.14	2.23	1.78	1.64	1.46	2.46	1.08	0.97	0.70
Iron and aluminum oxide.....	0.57	0.75	0.64	0.61	0.61	0.36	0.56	0.68	0.46	0.46
Difference.....	+1.13	0.12	0.36	0.57	.91	0.95	.28	.04	.63	.07
Totals	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00

Lab. No. 662 is an analysis of an average of samples taken all over George Lake, Sec. 13, T. 21 N., R. 1 E.; of a property of 380 acres, 200 are covered with boglime.

Lab. No. 659 is an analysis of the average of 30 samples from Edwards Lake, Sections 21, 22, 27, 28, of the same township. There is said to be 240 acres of marl that averages 20 feet thick. The outlet from the lake to the Tittabawassee has been cleaned out, draining the boglime.

Lab. No. 663 is an average analysis from Chapman Lake in Sections 31 and 32 on the same township. There is said to be some 160 acres of boglime here, also readily drained.

Lab. No. 623 is an analysis of an average sample from Plummer Lake, near Sec. 8 of the same township, close to the Hauptman branch of the Michigan Central. There is only about 40 acres, but of very nice lime, and in conjunction with a clay deposit elsewhere analyzed.

Lab. No. 891 is from Crapo Lake, Sections 7, 8, and 16, T. 22 N., R. 2 E. Here there are said to be about 240 acres of lime with an average depth of about 12 feet, covered with a top coat of peatmuck about six inches thick, and a growth of grass and brushwood. It is said that about two-thirds of the body of marl occurs in a low swampy basin, an old filled lake, now traversed by several narrow

channels, with a small remnant lake here and there, the whole draining into Rife River in such a way that much of it can be easily drained.

Lab. No. 896 is from the same lake.

Nos. 892 to 895 are Mills Lake marls, Nos. 1 to 4, Sections 24 and 25, T. 21 N., R. 3 E. Here there is about 160 acres of marl, mainly in the lake under from three to fifteen feet of water, but the outlet, it is said, can be readily deepened. There is a slight growth of vegetable matter over in some spots, but there is said to be no muck topping.

The somewhat larger amount of organic matter in the Mills Lake and Crapo Lake analyses is attributed by Lathbury & Spackman, who collected and analyzed them, to the relatively superficial character of the samples, and consequent larger amount of vegetable matter.

ANALYSES BY R. C. KEDZIE.

Clays, Sample No.	7B	36
Sand	1.10	0.95
Silicate of alumina.....	46.70	45.66
Carbonate of calcium.....	15.30	18.40
Carbonate of magnesium.....	2.63	1.50
Oxide of iron.....	8.15	6.90
Water	25.00	24.00
Difference	1.12	2.69
Totals, 100.00.		

These analyses were of clay near Plummer Lake; see Lathbury & Spackman's analysis.

Marls sample.	Mills.	Crapo.
Calcium as carbonate.....	84.50	88.57
Magnesium as carbonate.....	2.20	1.50
Insoluble (as sand, etc.).....	1.00	2.00
Oxide of iron, etc. ....	.50	1.00
Difference (water and organic matter)	11.80	6.93
Totals, 100.00.		

These two samples from Mills Lake and Crapo Lake respectively, should be compared with Lathbury's analyses from the same place (891 to 896). The Crapo Lake analyses agree quite closely. The Mills Lake lime either contains more organic matter or is less dry.

CLAY ANALYSES BY F. S. KEDZIE.

Sample No.	Bay.	2.	Plummer.	I.	Standish.	3.
Silica	58.95	54.88	44.27	42.53	36.52	39.10
Aluminum oxide.....	14.45	6.80	12.88	11.12	8.63	12.23
Iron oxide.....	7.60	5.52	5.76	5.06	2.80	2.33
Calcium oxide.....	2.94	15.42	16.20	16.16	49.03	17.09
Magnesium oxide.....	.86	5.50	6.02	5.97	7.26	2.10
SO ₂	1.73	2.62	3.68	3.32	.....	2.92
Alkalies as K ₂ O.....	2.54	.....	.....	.....	3.46†	.....
Comb. water.....	7.50	9.26†	10.61†	14.60†	2.74	22.14
Organic matter and loss.	3.43	.....	.....	.....	19.28*	.....
Total.....	100.00	100.00	100.00	101.40	105.69	100.00

† Difference. * CO₂. ‡ Manganese tr.

With the exception of the first analysis, which is of a Bay County shale, and is a "good clay; it is entirely free from calcium carbonate, and is to be recommended for its content of silica and freedom from grit," the rest are surface clays with the usual large amounts of carbonates, and considerable percentages of magnesia. A number are, I believe, near Standish. No. 3 is from Plummer's Lake. Compare Lathbury & Spackman's analysis 675, which runs much higher in silica. The percentages of calcium and magnesium as carbonates are as follows:

Calcium carbonate.....	5.25	27.58	28.96	28.90	33.99	32.00
Magnesium carbonate...	1.80	11.51	13.84	12.50	15.25	6.49
	7.05	39.09	42.80	41.40	49.24	38.49

In the Standish analysis in which the CO₂ is determined, it will be noted that the sum of the calcium oxide, magnesium oxide and carbon dioxide is but 45.55 per cent, while the sum of the carbonates as above given, is 49.24, which shows that not all the calcium and magnesium oxide are combined as carbonates, but some, especially of the magnesia, probably are present as silicate.

CLAY ANALYSES BY R. E. DOOLITTLE.

Sample No.	5	11	C	"lift"
Coarse sand	2.00	11.60	1.00	14.70
Silica	42.56	40.76	44.02	44.29
Alumina	9.47	10.05	13.36	9.00
Iron oxide	3.56	2.70	1.82	2.60
Calcium oxide ...	15.15	14.80	17.28	14.45
Magnesium oxide.	5.95	7.45	2.60	6.26
Sulphur anhydride	1.06	1.73	2.36	1.50
Difference	20.25	10.76	17.56	7.20
Totals, 100.00.				

No. 5 is from Edwards township, No. 11 the same, but contains too much sand and gravel for cement making. C is the same in location. The other is from Chapman Lake.

These clays are all surface clays, with 35 to 40 per cent carbonates, and a high but variable percentage of magnesia. Owing to the large amount of carbonates it would be necessary to use a large amount of clay, and it would be hard to keep the magnesium as low as desirable, or, I fear, the composition uniform.

It is not intended to use any of these clays for cement manufacture, though similar clays have been sometimes endorsed.

CLAY ANALYSES BY LATHBURY AND SPACKMAN.

Sample No.	1-04	2-05	06	02	03	01	870	867	849
Silica.....	39.34	35.12	65.24	44.60	40.75	48.88	48.52	54.05	51.40
Iron and al. oxide	15.98	13.51	23.55	13.11	15.39	22.17	20.67	24.01	29.30
Lime.....	14.76	16.45	0.00	11.47	12.83	6.65	6.63	.12	.15
Magnesia.....	6.18	7.52	1.11	7.09	6.53	4.50	2.55	2.55	2.22
Loss on ignition.....	19.58	22.08	6.72	17.91	18.25	12.51	14.03	9.55	11.64
Difference (alkalies)....	4.26	5.51	3.37	5.82	5.04	5.29	7.57	9.40	6.08
Totals.....	100.00	100.00	104.99	100.00	99.20	100.00	100.00	100.00	99.21

*Including .79 sulphur.

Lab. No. 904, field No. 1—04 is from Mills Lake, about half a mile below the outlet. The lime as carbonate would be 26.35 and the magnesia 12.86. The area is about 80 acres, the depth over 30 feet.

Lab. No. 905, field No. 2—05, from the same place, the lime carbonate 29.39, and the magnesia 14.78.

Lab. No. 906, field mark 06, from hole No. 11, on the Leinberger land, Frankenlust township, Bay County, Sec. 2, T. 13 N., R. 4 E.

The first two clays are like those analyzed by Doolittle, surface clays, about 40 per cent carbonates. Large quantities would have to be used of them, the amount of magnesia would be undesirably large, and it would probably be difficult to keep a uniform composition. The next is a regular coal measure shale clay, and would probably be a valuable paving brick clay, as well as suitable for cement.

Lab. No. 897, field No. 02, from Michigan Clay Co., Frankenlust township, Bay County, in the northeast part. This is a surface calcareous clay, properly called marl, the lime would be 20.48 as carbonate, and the magnesia 14.82, or over a third carbonates, and the remarks above upon surface clays apply.

Lab. No. 898, marked 03, is from the Williams Clay Co., just north, and is an entirely similar surface clay, with 22.91 per cent calcium carbonate and 14.30 per cent magnesia carbonate.

Lab. No. 887, marked 01, is from Everett's at Corunna, and is also a surface clay with a considerable amount of carbonates, although perhaps because it is farther from the outcrop of the Eocarboniferous Limestones, decidedly less, namely, 11.87 of calcium carbonate and 9.50 of magnesium carbonate. It is also said to have no sulphates, which is rather remarkable! It is probably derived largely and not very remotely from a coal measure shale clay, like the following analysis.

Lab. No. 870, also a Corunna clay, but with much less of carbonates, so much so, that it can hardly be a surface clay.

Both this and the previous analyses are remarkably high in iron and alumina, but Prof. Campbell of the University of Michigan got similar results for clays of this district, which are 15 to 20 feet thick, have little sand and occur on high ground directly over shale, to wit: about 48 per cent silica, 16 of alumina, and 5 of ferric oxide. In some cases of very fusible shale there was as much as 25 per cent alumina.

Lab. No. 867 is a clay from south of Tawas City, in Iosco County. The form of the analysis indicates that like the analyses of pp. 40 and 41, in Part 8, it is practically of a shale of the Michigan series. The high per cent of difference undetermined is probably sulphates (gypsum) as well as alkalis. There is, however, some uncertainty about this sample.

Lab. No. 849 is from a boring one mile north of Goetz farm, Sec. 36, Monitor township, Bay County, T. 14 N., R. 4 E. The lime is remarkably low in proportion to the magnesia. There is some pyrite (0.79 sulphur) and the large loss on ignition and large amount of alumina and iron are noteworthy. It should be readily fusible. This is not at all of the fire clay type.

CLAY ANALYSES BY L. AND S.—CONTINUED.

Sample No.	814	815	725	726	727	728	863	816	822	833
Silica.....	55.06	47.83	37.75	42.71	61.13	54.93	41.38	39.81	43.53	41.00
Iron and al. oxide.....	30.53	26.21	13.13	14.92	26.90	31.43	27.02	18.57	14.71	17.19
Calcium oxide..	0.12	0.14	17.04	13.72	.12	.22	.52	3.74	12.69	12.79
Magnesium oxide.....	1.47	1.19	6.88	6.36	6.47	1.58	.90	5.20	5.65	5.68
Loss on ign. (organic matter and CO ₂ , etc.)	7.47	10.09	29.20	23.29	6.47	7.41	23.11	18.22	17.89	18.39
Difference (alkalies, etc.)..	5.35	5.54	.....	.....	4.42	5.43	7.07	4.45	5.53	4.95

No. 814, St. Charles shale, No. 1, is a coal measure shale of the fusible variety.

No. 815, St. Charles shale, No. 2, is similar but even lower in silica. The lime, it will be noticed, is extremely low.

No. 725 is another surface clay with similarly high per cent of carbonates (30.46 calcium carbonate + 13.07 magnesium carbonate) and low silica.

No. 726 is a similar surface clay; it is from Sterling, not Standish, No. 2, S. W. Arenac County, not far off. Calcium as carbonate is 24.56 and magnesia 12.09.

No. 727 is a light shale from the Bay County coal field.

No. 728 is said to be a dark shale from the same field. The iron must contribute with the organic matter to the darker color.

No. 863 is a shale from the Goetz land, Sec. 36, Monitor township, a coal measure shale. With the low amount of lime and magnesia characteristic of these shales, the large loss on ignition shows much organic matter (black shale), and it will be readily fusible.

No. 816 is from the Prairie farm, and I think the same deposit as No. 18 of Part I, though I cannot account for the discrepancy in silica. The lime as carbonate would be 24.38 and the magnesia 9.90,—about the usual 35 per cent carbonates of the surface clays.

No. 822 is a surface clay from Crapo Lake, T. 22 N., R. 2 E., an average of Section 9.

No. 823 is from the same locality, an average of Section 10.

The former has about 22.66 per cent calcium carbonate and 11.65 magnesium carbonate, and the latter has 22.83 per cent calcium carbonate and 11.70 magnesium carbonate, or as usual, about one-third carbonates.

CLAY ANALYSES BY L. AND S.—CONTINUED.

Sample No.	643	(?)	712	713	658	676	660	661	675
Silica.....	41.54	41.58	43.35	42.95	44.69	47.59	44.40	39.28	52.75
Alumina.....	13.15	9.96	14.43	14.98	9.90	10.20	9.54	13.32	11.34
Ferrie oxide.....	4.83	4.20	.....	.....	4.29	2.71	2.71	4.57	.....
Calcium oxide.....	13.98	15.02	18.58	148.78	12.96	13.75	14.04	14.21	12.88
Magnesium oxide.....	5.45	6.35	5.71	5.84	5.98	5.15	6.09	0.94	4.75
Loss on ignition (water and organic).....	17.92	19.08	.....	.....	17.71	16.38	6.09	18.83	14.53
Difference (alkalies, etc.).....	3.18	3.85	22.93	22.50	4.47	6.93	23.22	8.87	3.87
Totals.....	100.00	100.00	100.00	230.00	99.91	102.71	106.09	100.00	100.02

Lab. No. 643, clay 3—B, is a surface Bay County clay, with 24.81 calcium carbonate and 11.39 magnesia carbonate.

The next sample is similar, but has even more carbonates, —26.82 of calcium carbonate and 13.30 of magnesia, over 40 % in all.

Lab. No. 712 is a clay from near George Lake, T 21 N., R. 1 E.,—also a surface clay with 24.25 calcium carbonate and 11.96 magnesium carbonate.

Lab. Nos. 658 and 676 are both near Edwards Lake in the same township, the former from a clay bed "directly at the outlet of the lake in Sections 25 and 27,—and has been found to cover a tract one half mile square, and is of good depth, though underlaid to some extent with sand and gravel." This has 23.14 calcium carbonate and 12.54 magnesium carbonate.

No. 676 comes from a deposit about one mile east and down the outlet stream, of over 40 acres area and over 20 feet depth. This has 24.57 calcium carbonate and 10.80 magnesium carbonate.

Lab. No. 660 comes from near Chapman Lake, Sec. 7, Clement township, Gladwin County, T. 20 N., R. 1 E.,—a bed "over 40 feet thick, explored for over half a mile." Here again we have 25.07 calcium carbonate and 12.78 magnesium carbonate.

Lab. No. 661 comes from Sec. e, near by and has 25.97 calcium carbonate and only 1.92 magnesium carbonate. This is the lowest in magnesia of any of the surface clays.

Lab. No. 675 is of a clay from Plummer Lake, "in direct conjunction with the marl at the east end of the lake, and runs down under the marl at the southern side. The clay deposit is covered with about three feet of surface earth and is 40 acres in extent," averaging eight feet in depth.

Taking the set all together, we see that these surface clays rarely run less than 35 per cent or over 45 per cent of carbonates, but that the amount of magnesia varies materially, though it is usually over a third of the carbonates.

The uncertainty as to whether the percentages will remain uniform through a deposit, and the difficulty in getting a satisfactory analysis from the resulting cement, are what make the surface clays not, except possibly in rare instances, to be recommended for the making of cement. All these clays will fuse readily.

12. The Great Northern Portland Cement Co.

Organized 1899, capital, \$5,000,000, in 50,000 shares; there was \$2,000,000 preferred stock bearing 7½ interest, the balance common. In selling the preferred, a bonus of one-half share of common was given. Located at the company's village of Marlborough, two miles south of Baldwin, on the Pere Marquette R. R., Secs. 14 and 15, T. 17 N., R. 13 W., Lake County. They also own or control about 6,200 acres in the neighborhood, about 3,500 of them with bog lime, to wit: Sec. 13, T. 16 N., R. 13 W., lakes and lime; Sec. 15, and most of 21 and 10, T. 17 N., R. 12 W., also the N. ½ of the N. E. ¼, Sec. 18, surface clay, especially on 10, and marl; N. ½ of N. W. ¼ of Sec. 36; N. ¼ of Sec. 34; Sec. 27; Sec. 14; E. ½ of Sec. 15 and part of Sec. 10 all in T. 17 N., R. 13 W. Also parts of sections 23, 26, 27, 34, 35, T. 18 N., R. 13 W.; Sec. 27 and parts of 26, 34, 35, T. 19 N., R. 13 W., all marl lands. There are in all some 17 lakes, generally with low shores, surrounded with a rim of marsh or tamarack growth underlain with marl. One of these lakes is said to have water from one to six feet deep with marl from 20 to 58 feet deep. In general the deposits are 18 to 20 feet deep.

The first unit, now nearly complete, to which one or two more may be added later, has a capacity of 4,000 barrels a day, with 24 rotaries.

The following is Booth, Garrett & Blair's report:
Great Northern Portland Cement Co.,
82 and 84 Griswold street, Detroit, Michigan.
Gentlemen:—

Following your visit to this city in September, we received in due course your letter of instructions to make a thorough investigation of your cement property in Lake County, Michigan, and agreeably therewith, our Mr. Whitfield made an extended examination of the property, taking a large number of samples, gauging and locating the deposits and establishing their quantity and accessibility. Since his return, we have made analyses of the samples selected, and have burned three lots of cement from suitable mixtures of these samples and subjected these cements to analyses and to numerous physical tests. All this data is now in your hands in a series of preliminary reports.

We are now prepared to render final report on the broad project which you have in view, to wit: the construction of a modern plant of large capacity for the manufacture of Portland cement, near Baldwin, and this report follows:

Raw materials.—Regardless of large tracts of land which you have since purchased, we find that the property examined by Mr. Whitfield contains deposits of raw materials suitable for high grade Portland cement, and in sufficient quantity to supply a large plant for many years. These raw materials are white shell marl and blue clay.

The clay "D," used by us so successfully in making cements, is found in immense quantities on Sec. 10, T. 17 N., R. 12 W. This locality is shown in relation to the marl tracts in the map attached to this report.

Cement.—An expression of opinion on the quality of raw materials for cement may in some cases be quite sufficient, but will never be so convincing to practical minds as an actual test. For this reason we have burned from your raw materials three successive lots of clinker with increasing percentages of lime, and have tested the cements with results as follows:

Samples.	No. 1.	No. 2.	No. 3.
Nominal lime content.....	64% 660 lbs.	65% 710 lbs.	66% 930 lbs.
7 day tests of neat briquettes.....	614 " 670 " 686 " 623 "	730 " 673 " 820 " 890 "	974 " 924 " 952 " 946 "
Average.....	641 lbs.	776 lbs.	945 lbs.
7 day tests, 1 cement to 3 sand.....	266 lbs. 282 " 270 " 262 " 250 "	396 lbs. 370 " 370 " 410 " 350 "	460 lbs. 424 " 432 " 448 " 430 "
Average.....	266 lbs.	379 lbs.	437 lbs.
Samples.	No. 1.	No. 2.	No. 3.
Nominal lime content.....	64%	65%	66%
Specific gravity.....	3.03	3.04	3.06
Initial set.....	1°50'	2°10'	1°25'
Final set.....	3°40'	4°40'	4°0'

ANALYSIS.

Silica.....	24.01%	24.84%	23.87%
Alumina.....	5.51%	4.51%	4.82%
Iron oxide.....	2.38%	1.74%	2.30%
Lime.....	63.91%	66.66%	66.01%
Magnesia.....	3.40%	3.10%	3.03%

28 day tests were made from lot No. 1 with results as follows:

	Neat.	1 cement to 3 sand.
28 day tests, sample No. 1.....	952 lbs. 918 " 980 "	470 lbs. 450 " 466 "
Average.....	960 lbs.	469 lbs.

Very truly yours,
BOOTH, GARRETT & BLAIR.

The clay bank in Sec. 10, T. 17 N., R. 12 W., covers some 400 acres. From the amount of magnesia in the finished cement, it would seem that there is as usual, some six or seven per cent of magnesia in the clay, though I have seen no series of analyses of it. This rises as a hill of clay, a bit of glacial deposit, some 90

to 150 feet high, in the midst of prevailing sand and gravel. It is said to be free from grit. Gravel for concrete was found in the excavations for the plant.

In the beginning, the lime of North Lake, right by the mill, will be used, and the clay shoveled by steam shovel and transported in special cars, and the marl in scows.

Prof. R. C. Carpenter reports in part, as follows:

"I find that the marl exists as is represented, and is found in a great number of lakes and surrounding marshes, occurring to a depth varying from 20 to 70 feet. The marl in every case is of excellent quality and free from any material which would interfere in the manufacture of cement. The clay deposit is located a short distance from the center of the marl deposits and the site of the works. The clay has been thoroughly tested by reputable chemists, and is found to possess all desirable qualities required, both as shown by analysis and by actual trial in the manufacture of cement. The clay deposit is of almost unlimited magnitude and would supply the plant for more than a century, even when working on a scale of 12,000 barrels per day. The examinations of the deposit have convinced me that the materials are all that has been claimed, both as to quality and quantity."

13. Detroit Portland Cement Co.

Organized March 7, 1900. Capital, \$1,000,000.

From the Fenton Independent of March 31, 1900, comes the following item (see Plate XXI and Fig. 23):

Deals for marl land on which the Becker Bros. hold options in Fenton township are being closed up. The lands embrace the marl on 110 acres of the McKugh farm at Mud and Silver Lakes, and the marl on 74 acres on the Beals farm at Silver Lake, and the marl on 89 acres on the Latourette farm on Mud Lake. Only the marl rights are purchased, the price paid Beals being \$2,500, and the price paid Latourette being \$800. The marl rights to 30 acres of the Tunison farm at Silver Lake were purchased for \$900.

This factory is built on the line of the Grand Trunk. It is to be an eight rotary plant, with provision for enlargement (compare Plate V). The plant is designed by Lathbury & Spackman, and illustrated in their work, "Engineering Practice," already referred to so often. Their description is as follows:

The plant of this company, located at Fenton, Michigan, is now nearing completion. The mill is designed to manufacture Portland cement from a mixture of marl and clay by the wet process, and possesses some distinctive features not embodied in the marl plants heretofore erected.

The buildings substantially constructed of brick and steel, are fire-proof, and so designed that the material in process of manufacture will move in one direction from the time the raw materials

are brought in at one end, until the cement is shipped out from the packing house at the farther end. All the buildings have clear spans. The mill is located on a slight elevation overlooking the large marl deposits of Mud and Silver Lakes, owned by the company. The clay is obtained from pits a few miles distant from the plant. The marl is dredged from the lakes and loaded into cars of two cubic yards capacity which run on a track along the edge of the lake. The cars are then drawn by cable hoist up an inclined trestle into the mill and dumped into the hopper over the stone separator. The clay is brought into the plant by rail. The two ingredients after passing through separate preliminary preparation are mixed together in the proper proportions and ground in tube mills. Large concrete storage pits contain the marl and clay before mixing, and similar pits are provided for the mix and ground slurry. It has heretofore been the practice to pass the clay through some suitable dryer, then after it has been ground to an impalpable powder, to mix this powdered clay with the marl. In this plant, however, the clay is unloaded directly from the cars into a disintegrator, from which it discharges into a pugging conveyor which carries it to a wash mill, where it is reduced to a thin sludge.

The marl passes, first, through a stone separator which reduces it to a smooth plastic state and removes any roots, grass or stones which may have been brought up by the dredge bucket. It is then stored in the marl pits. Each pit is provided with an agitator to prevent settling. The marl and clay are pumped to the mixing pits in proper proportions and thoroughly agitated. From these pits the raw mix is pumped to iron tanks above the tube mills, from which it is fed to the mills by gravity. After being ground in the tube mills, the slurry is discharged into concrete storage pits which supply the kilns, the slurry being pumped to a stand pipe from which it is fed at a constant pressure directly into the kilns. After passing through the kilns, of which there are eight, the clinker falls into air-tight, self-emptying concrete cooling vaults, located below the kiln room floor and directly under the discharge from the kilns, two vaults being provided for each kiln; the Lathbury & Spackman patent regenerative clinker cooling apparatus being used. Cold air is drawn in through openings in the bottom of these vaults, and passing upward through the clinker cools it. The hot air being exhausted from the top is forced into kilns mixed with pulverized coal, thus utilizing the heat contained in the clinker for burning. The clinker is drawn out at the bottom of the vaults into cars which run on tracks located in the tunnel below the clinker cooling vaults. These cars are run out of the tunnels and raised by an electric lift to the level of the top of the bins feeding the clinker ball mills, and the clinker is discharged from the cars into these bins. After passing through the ball mills, the partially ground clinker is elevated and conveyed to the bins supplying the tube mills. From these mills it is elevated and conveyed to the stock house and distributed in the bins. The stock house is equipped with Lathbury & Spackman self-discharging bins, described elsewhere in detail.

Conveyors in the tunnels of the stock house carry the cement to the packing room, located at the extreme end of the building, and deliver it to the bins over the packing machine. The packing department, fully equipped with both barrel and bag packing machinery, has a capacity of 1,500 barrels of cement per day.

The power house, located close to the main building, is equipped with four 200-horse power vertical water tube boilers. Two 500 horse power compound condensing engines, direct connected to two 300 K. W. direct current generators are located in the engine room. An auxiliary 150 K. W. direct connected dynamo and engine is provided to furnish current for lighting and power when the plant is operating under light loads. The power plant is completely equipped with the usual accessories, such as switchboards, pumps, condensers, etc., and special attention has been paid to securing economy in the generating of power. The entire plant is electrically driven, the motors being distributed throughout the plant, each machine being belted direct to its own motor.

ANALYSIS OF THE CLAY AND THE MARL

	Marl	Clay
Silica, SiO_2.....	.96	54.70
Alumina, Al_2O_3.....	.44	18.80
Iron, Fe_2O_3		7.17
Lime, CaO	52.43	3.87
Magnesia, MgO	1.06	9.80
Carbon oxide, CO_2	42.90	.96
Difference.....	1.52	
Total.....	100.00	100.00

14. Egyptian Portland Cement Co.

Organized June 30, 1900. Capital, \$1,050,000, in \$10 shares. Also bonds, \$350,000. The officers are, George A. Foster, president; J. Fletcher Williams, vice president and general manager; C. B. Shotwell, secretary, and E. D. Kennedy, treasurer.

The factories are at Fenton and Holly. Robert W. Hunt & Co., are engineers and W. H. Hess, chemist.

We reprint many of the careful surveys which were made of the company's lime lakes. One (Plate XXI) is of Silver Lake, the Fenton property, and another, (Fig. 21) is Raffeele Lake, the Holly property of the same company.

In Plate XXI the bluffs which mark the original margin of the lake are shown as in Fig. 13, and if we compare the outline of the lake with that shown in the county atlases from the original land office surveys, we find it entirely different. Apparently a good deal

of this is due to the filling up of the lake by the deposits of boglime, isolating "daughter lakes," as Davis has described them, from Littlefield Lake. It is possible, however, that a change of lake level

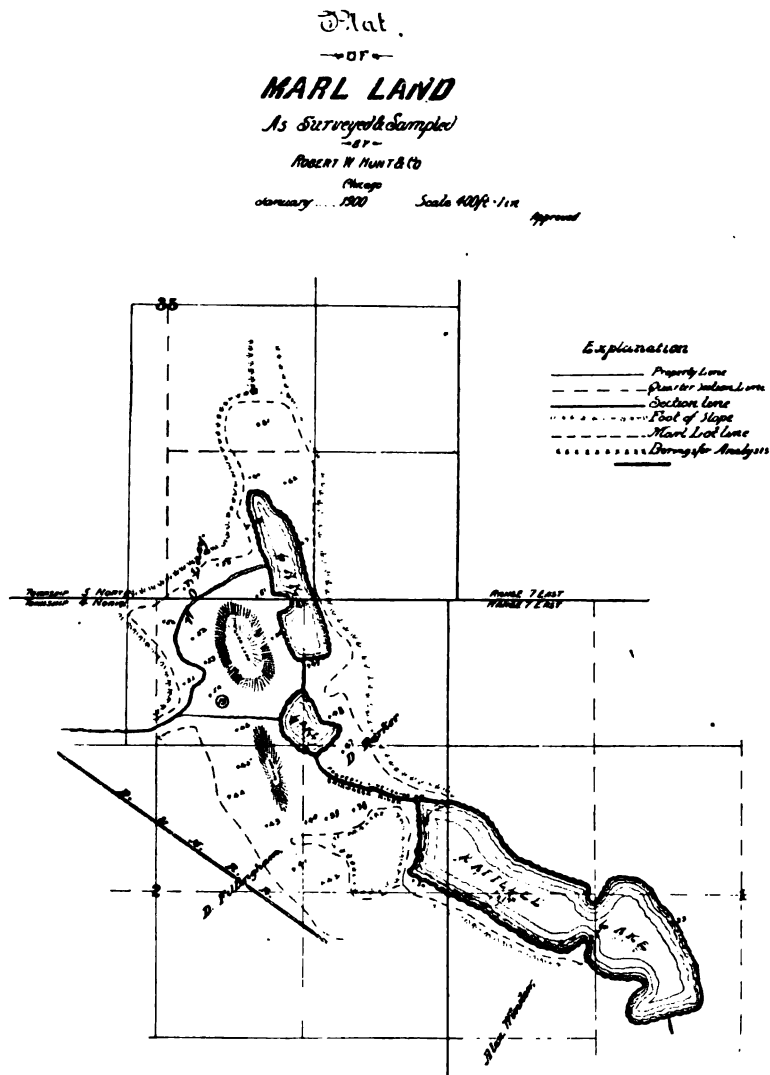


Fig. 21. Plat of Raffeelee Lake, Holly Township, Oakland Co.

may also have been an important factor. Finally, but not least important, the surveyors in meandering these marsh bordered lakes, which are often full of rushes, find it very difficult to determine where marsh ends and lake begins. We also reproduce reduc-

tions of careful surveys of Runyan Lake, Sections 9 and 10, T. 4 N., R. 6 E. (Fig. 22), and of Mud Lake, just north of Silver (Fig. 23).

Also of lakes on sections 27, 28 and 30 and 29 of Holly township (Figs. 24 and 25).

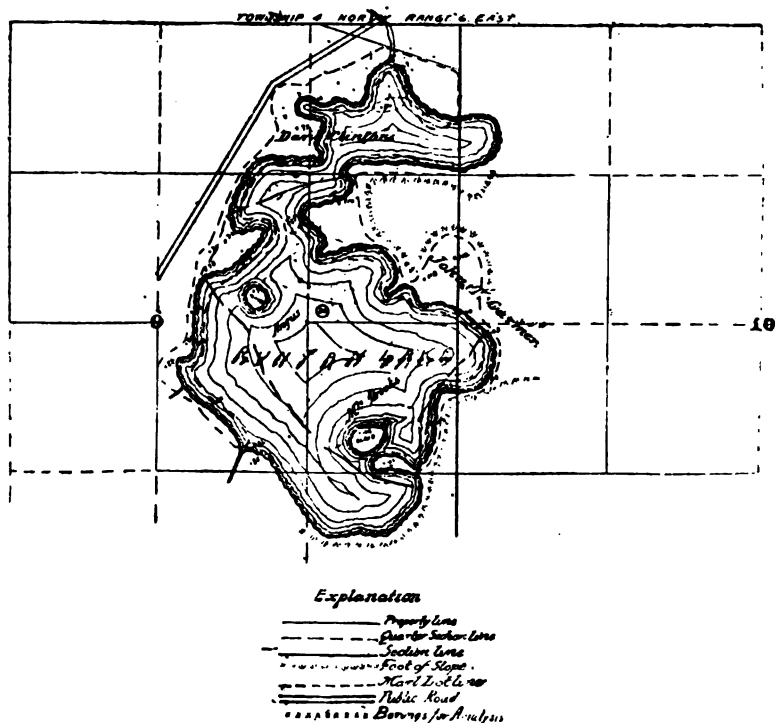


Fig. 22. Runyan Lake. T. 4 N., R. 6 E., near Fenton.

There is peat in connection with these deposits "partially overlying and directly contiguous, which it has been proposed to use as fuel, though it is not at present seriously planned. The coal and very probably the shale will come from the neighborhood of Corunna. The Grand Trunk and the Pere Marquette system cross at Holly.

A resurvey after some years, of such of these properties as may not have been seriously touched, will give important light on the growth of the deposits. Extracts from the prospectus, Robert W. Hunt & Co.'s report, are as follows:

Report dated Jan. 30, 1900.

We beg to submit the following report in full on the survey and investigation of the marl lands situated near the cities of Fenton and Holly, Michigan.

The marl land surveyed and sampled consisted of four separate deposits. The first and largest, is in the southeast corner of Genesee County, two miles west of the town of Fenton, and extends south into the northern part of Livingston county (Plate XXI).

The second is in Oakland County, two miles east of Fenton, and about midway between Fenton and Holly.

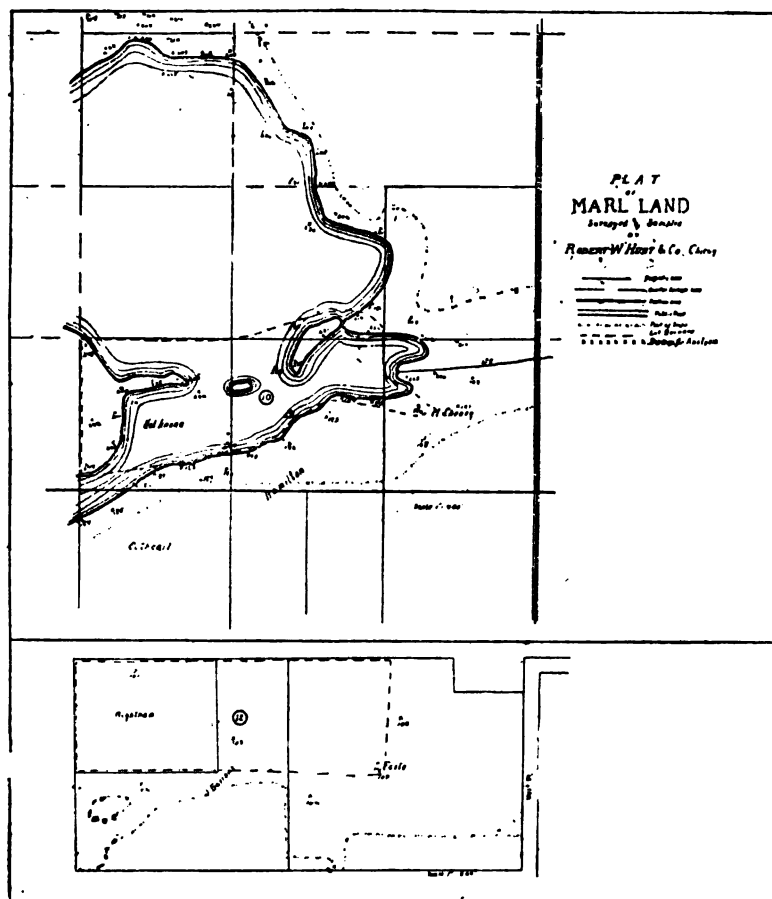


Fig. 23. Mud Lake. Sec. 22, T. 5 N., R. 6 E.

The third deposit is in and north of the town of Holly.

The fourth deposit is about two miles southeast of Holly on Raffle Lake (Fig. 21).

The first tract consists of Runyan Lake (Fig. 22), Marl Lake, Upper and Lower Silver Lake, a part of Mud Lake (Fig. 23), Squaw Lake, and the low swamp land contiguous to these lakes, together with a strip of land in the town of Fenton. As a rule the hills surrounding these lakes are high and steep, and the slope of the marl

deposit is quite abrupt, which latter is also true of the lake bottoms. Many bars of marl, covered with only a few inches of water, extend into the lakes, but just off these bars the water is deep.

The second tract (Fig. 24) consists of marsh land around Warren Lake and several small ponds near by, Dickson Lake and the two Mineral Lakes. The hills around these are also high and steep and the shores are abrupt.

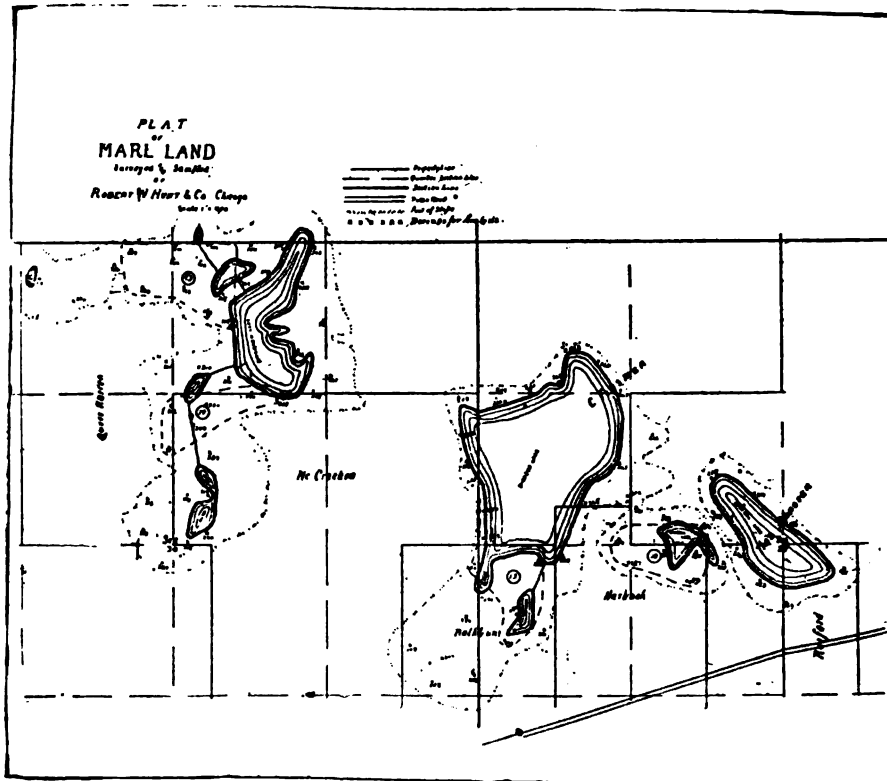


Fig. 24. Warren, Dickson, Mineral and adjacent lakes and marl beds. Sections 29 and 30, T. 5 N., R. 7 E.

The third tract (Fig. 25) is in and around Bevin Lake and Bush Lake. There are no hills around these lakes, and the marl deposit is shelving, and the shores are not abrupt. A large part of Bush Lake is only a few feet deep. There is no tamarack or underbrush.

The fourth tract is along the south edge and west end of Rafflelee Lake, including the swamp lands just west and northwest of Rafflelee. Part of this swamp land is heavily timbered, and the average stripping is about two feet.

The first tract is cut by three highways and the Detroit, Grand Haven & Milwaukee railroad track, together with the public road which lies between Silver and Mud Lakes. Another road is just south of Silver Lake, and still another south of Marl Lake.

The Detroit, Grand Haven & Milwaukee railway runs alongside of Raffle Lake. There are no highways crossing this tract, but it will probably be easy to secure one on the section line.

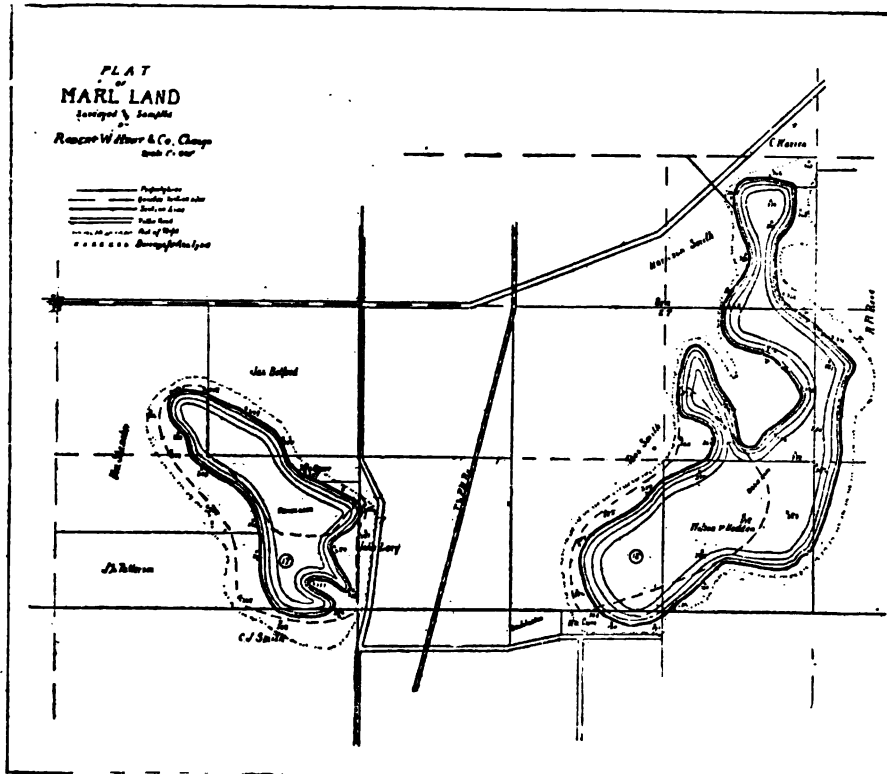


Fig. 25. Bush Lake, Sec. 27, T. 5 N., R. 7 E, and adjacent marl beds near Holly.

In determining the extent of the deposits, about four hundred additional test holes were sunk, from which no samples were taken.

The following statement shows total acreage:

Examined.	Sampled and Mapped.
Tract No. 1.....	976.0 acres
Tract No. 2.....	190.6 acres
Tract No. 3.....	163.6 acres
Tract No. 4.....	239.5 acres
	<hr/>
	1569.7 acres

Considering the results obtained from the chemical analysis of the marl, lots or deposits of marl have been located wherein the marl, as shown by the analysis, is of such composition as is required to make good cement.

The total amount of marl in the foregoing lots, upon which we report favorably, is 14,350,720 cubic yards, which is enough to manufacture about 28,700,000 barrels of cement.

The following tables show the maximum, minimum, and average determination of the samples from the accepted lots, together with the average depth of marl, quantity of stripping, and quantity of marl in each lot.

LIST OF LOCALITIES AND MILLS.

279

[illegible]

The best locations for cement plants are upon the Grand Trunk railway, between Silver and Mud Lakes at Fenton, and upon the same road at Raffeelee Lake, just east of Holly. At the latter point the Pere Marquette system would doubtless be glad to build a switch into the plant, giving it the benefit of junction point rates, which could probably be extended to include the Fenton plant as well.

From the chemical analysis of marl, its desirability for the manufacture of cement is determined. The analysis also gives data for determining the amount of clay that should be mixed in order to give good results. A large percentage of silica is not desirable, but four to five per cent is not prohibitive, providing it does not vary to too great an extent. The amount of iron and alumina oxide that is detrimental depends upon the analysis of clay with which the marl is to be mixed. The magnesium carbonate should not be over four to five per cent, which, of course, will be reduced in the finished cement between two and three per cent.

If the amounts of silica, iron and alumina, and magnesia in a body of marl are small, a comparatively large variation in the calcium carbonate can be allowed, because its percentage will vary almost directly as the amount of organic matter.

We would respectfully recommend that all material possible be conveyed by mechanical means, and that the labor account be reduced as low as possible.

(Signed) ROBT. W. HUNT & CO.

Lansing, October 1, 1900.

Egyptian Portland Cement Company,
Detroit, Michigan.

Gentlemen—I beg leave to make the following report of tests of cement made from clay and marl received from you from Fenton, Michigan:

FINENESS.

Passing No. 50 mesh sieve.....	100%
Passing No. 100 mesh sieve.....	98

SETTING TIME OF NEAT CEMENT.

Initial set.....	2 hrs. 10 min.
Final set.....	4 hrs. 40 min.

CONSTANCY OF VOLUME TESTS.

Cold water pats.....	Sound and hard.
Boiling water pats.....	Sound and hard.

TENSILE TESTS OF STANDARD NEAT BRIQUETTES.

(1 square inch section.)

Serial No.	Hardening Period.			Neat Briquettes.	Sand Briquettes, 1:3.
	In Air.	In Water.	Total Days.	Strength in lbs.	Strength in lbs.
1165.....	1	0	1	270	50
1165.....	1	1	2	440	82
1165.....	1	2	3	545	135
1165.....	1	3	4	610	168
1165.....	1	4	5	680	190
1165.....	1	5	6	755	212
1165.....	1	6	7	815	245
Government Standard..	.....	.....	.....	400	160

Very respectfully,
(Signed) R. E. DOOLITTLE,
Chemist.

Lansing, Michigan, Oct. 1, 1900.

Egyptian Portland Cement Company,
Detroit, Michigan.

Gentlemen—I have been investigating the peat question, and submit for your information the following table:

	Carbon.	Hydrogen.	Oxygen.	Calorific or heat unit value.	Capacity of high heat, or calorific intensity Centigrade.
Wood.....	50.18	6.06	43.74	4212	2380°
Peat.....	61.53	5.64	32.82	5654	2547°
Lignite coal.....	67.86	5.76	23.39	6569	2628°
Bituminous coal.....	79.38	5.34	13.01	7544	2694°
Charcoal.....	90.44	2.91	6.63	8003	2760°
Anthracite.....	91.86	3.33	3.02	8337	2779°
Coke.....	97.34	0.49	.....	8009	2761°

In examining this table, note the column designated "Calorific Intensity," and notice you can get as high heat with peat as you can with bituminous coal, lacking 150 degrees Centigrade, and the conclusion is therefore warranted that you can burn Portland cement with dried peat as rotary fuel. It would not cost over twenty cents per ton to prepare peat for rotary work, using waste heat as a drier. The grinding would be very easy.

Yours truly,
(Signed) W. H. HESS,
Chemist.

Twentieth Century Portland Cement Company.

Organized March 2, 1901. Capital, \$750,000.00. Office at Fenton and plant about four miles from the village, and stock said to be
36-Pt. III

mainly held there. It is said that marl options are held on Runyan Lake, mainly in Sec. 9 (see Fig. 23), and elsewhere, amounting to 526 acres, and 9,500,000 cubic yards. This is not a very large supply and so far as I know, this and the following companies and locations referred to are not very near production.

Zenith Portland Cement Company.

Organized July 17, 1900. Capital \$700,000. Bonds \$300,000. The board of directors were Marshall H. Godfrey, B. H. Rothwell, G. Johnston, E. T. Allen, Stowe, Fuller & Co., R. H. Evans, E. J. Foster.

The following are extracts from reports of engineers:

Extract from prospectus of the Zenith Portland Cement Co.:

I have spent six months in Michigan in the examination of marl deposits, and have no hesitancy in stating that the Grass and Tims Lake deposits are far superior, both in quality and quantity, to any deposit I have examined. I estimate that there is enough marl in this deposit to make 30,000,000 barrels of high grade Portland cement, or enough to supply a factory of 1,000 barrels per day for over 100 years.

The banks of this phenomenal deposit are adjacent to the M. C. R. R., and well adapted by nature for a solid foundation and favorable location of the plant. Close at hand is found a very fine deposit of clay, which was originally used in the manufacture of brick, but will now be used in the manufacture of cement.

Having both of these raw materials so close at hand, a high grade cement can be made here cheaper than any other place I know of.

T. C. BEEBE, C. E.

Cleveland, Ohio, July 23, 1900.

The Zenith Portland Cement Co.,
Detroit, Michigan.

Gentlemen—In answer to your letter of inquiry in regard to the marl bed at Grass Lake, Michigan, I would say that I have twice made an examination of this bed, and have had thorough analysis made from different sections. I have been over most of the marl beds in Michigan, and consider the Grass Lake bed equal in quantity of any in the State. As to chemical analysis, it runs about the same as the Brownson and Coldwater beds, but has the advantage of being much finer in texture. Ninety-eight per cent of this marl in its natural state will pass 20,000 mesh sieve, leaving only a very small residue, which is mostly organic matter, and will burn out in the rotaries. This fineness would save considerable wet grinding machinery. This marl is finer in its texture naturally, than any marl I know of now being used, even after grinding. This would insure a very fine mixture, and the very highest grade of Portland cement, as fineness of mix is one of the most important items in the manufacture. The marl bed itself is nearer the railroad than any I know of in the State. It needs no stripping, which will save much expense in handling. A factory can be located at this point

to handle material both to and from the factory, of fine grade and cheaper than any place in this country.

Yours very truly,

C. B. STOWE.

The analysis of the Grass Lake clay is entirely satisfactory and the quantity is abundant.

Our marl has been repeatedly and carefully analyzed, and following results were universally obtained:

Silica (SiO_2).....	1.22
Iron and aluminum ($\text{Fe}_2\text{O}_3+\text{Al}_2\text{O}_3$).....	.61
Carbonate of lime (CaCO_3).....	95.13
Magnesium carbonate (MgCO_3).....	2.04
Sulphuric acid.....	.26
Organic and water, etc.....	.74
	<hr/>
	100.00

It has a residue of less than two per cent on a sieve of 40,000 meshes to the square inch, thereby saving considerable expense in grinding the raw material; and as there is no muck or organic matter overlaying it, it can be excavated and conveyed to the works at a minimum cost.

The company's property virtually includes all of both Grass and Tims Lake, on which the original owners guarantee an average depth of 20 feet of marl on 400 acres. On this basis Grass Lake alone contains enough marl to supply a factory of 1,000 barrels per day capacity for 75 years, and Tims Lake enough more to supply the same demand 37 years. This marl requires no stripping. There is ample water to float our dredges, on each of which will be placed a pug mill.

The marl beds of this company lie in Sections 20, 29 and 30 of Grass Lake township, T. 2 S., R. 2 E. (Fig. 26), on the east side of Jackson County. Portage Lake and other lakes of this region are said to contain some marl, but this bed has the advantage of being close to the Michigan Central railroad, so that but a few hundred feet of siding will be necessary. At first, in the prospectus, the factory site was placed at the point marked A in the map, but now the foundations are at the point marked B.

Grass Lake is prevailingly shallow. The deeper holes do not appear to be over five to ten feet deep, and large areas are less than three feet deep. Over most of the lake bulrushes (*Scirpus lacustris*) are growing more or less scattered. In a general way they are most thinly scattered over the deeper holes, and these are points where the marl is covered by most water and appears to have most

organic matter. On the figure their distribution, i. e., that of the marl which comes close to the surface and appears to be better is

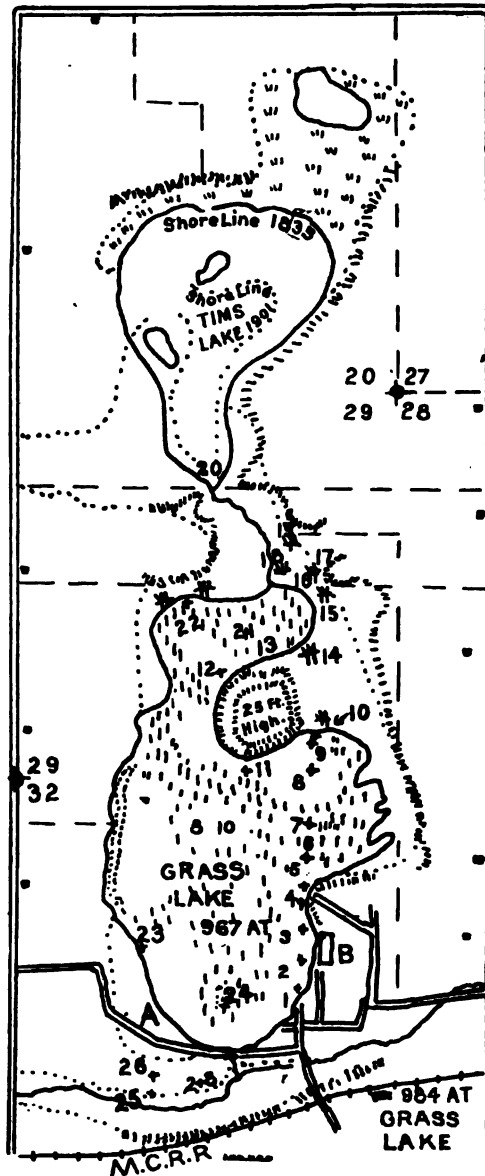


Fig. 26. Sketch of Grass Lake, T. 2 S., R. 2 E. Property of Zenith Portland Cement Company. The numbers are references to tables of soundings, not of depths.

indicated. When the marl surface comes within a foot or so of the surface, *Sagittaria* and other plants join and soon the marl becomes

covered with a peaty layer extending over the marl, ending abruptly in a vertical wall a foot or two high. Between localities 10 and 14 extends a tamarack swamp. At 14 good yellow marl is found beneath four feet of muck and sand, and at 10, which was at the inside edge of the belt of rushes and pond lilies, and at the beginning of that of tussocks, ferns, and ordinary swamp vegetation, there was marl close to the surface and over eight feet deep, so that the point 25 feet high with steep gravel banks, and shores terraced on the west side, which cuts off the northernmost bay of Grass Lake was once an island but is now joined to the shore on the east by this marl bottomed tamarack swamp.

A similar marginal bog, a hundred feet wide, Soundings 15, 16, 17, and 18, lines the north shore, covering marl which is quite thick, but it does not extend up to Tims Lake, as might seem probable from the connecting marsh, and sluggish stream which joins the lakes, because at 18 there is eight feet of peat, and at 19 there is only a trace of marl under the peat at six feet,—below which is sand.

The marl is quite extensively covered with the creeping vine-like stems of *Chara*, which are brittle with coats of lime. The deeper holes are more likely to be covered with a darker green plant (*Potamogeton*).

The west shore is sandy or gravelly where dotted on the map. The land rises gently and the lake bottom is not marly. The water along the edge made a suds, showing an abundance of organic matter. In general the water of the lake seemed full of organic matter and was green rather than blue. Shells did not appear remarkably abundant on the marl beds. On the east side of the lake a point projects with steep bluffs, near which the marl appears to be thinner, poorer and mixed with sand (soundings 1 to 4), and it is said that a shoal streak extends across the lake. North of this point the lake deepens to four feet of water, then rises to a heavy bed of marl (sounding 7), then deepens very slightly.

It is not at all likely that this lake was originally abnormally shallow, and there is every indication that its present shoal character is due to its being filled up with lime, mainly deposited by the *Chara* growth from variable depths,—over a large part of the lake doubtless over 13 feet deep. There are about 560 acres of marl or more.

The following is a tabulation of the results of the soundings:

	Water.	Peat or muck.	Marl.	Bottom.	Samples.	Remarks.
1.	4 ft.	2	2	6' sand	6'	
2.	4 "		7+		9'	
3.	3 "		5+		5	Sandy, shells
4.	2 "		crust	2 gravel		
5.	4 "		4+			
6.	4 "		4+			
7.	2 "		6+			
8.	3 "		5+			
9.	1 "		5	6	3' and 5'	
10.	1 "		7+		8'	
11.	2 "		11+			
12.	4 "		4+			
13.		4	+			Mucky marl.
14.						
15.	6 in.		6+		6'	
16.	1 ft.	1	6+			
17.			?			
18.		8				
19.		6	Trace at 6	6 sand		
20.	5 ft.			gravel		
21.	5 "		+			Sludge.
22.		2	6+			Very good.
23.	2 "	2	3½	5½		Sandy.

The auger reached only 8 feet.

In Tims Lake (we had no boat there), the marshes surrounding the lake seemed very extensive and it appeared as though they connected the islands shown,—in fact the shores appeared somewhat like the dotted line of Fig. 26.

The general aspect of the lake, however, is like that of Grass Lake.

The temperature of the marl sample at eight feet at sounding 10 was 58°, while the water a foot or less deep was 71° F. and the air 83° F. At sounding 22 the temperature of the marl sample at eight feet was 66° F. During the day the water temperature warmed up from 79° to 83°. No material difference could be noted in the water at the surface and five or ten feet deep, for there was a fair southwest breeze.

It is said that the company have clay lands in Ohio. There are brick clay pits to the south of this lake in the village of Grass Lake, and in the flat immediately adjoining the lake to the south. Soundings 25 to 28, there are some smooth pebbleless clays, an analysis of a sample of which is given below, from the grass roots down, though in sounding 25 at six to seven feet down, a streak of very fine-grained quicksand was found.

The clay at the lake is the ordinary surface calcareous clay of Lower Michigan, the finer part of a rock flour derived from almost all kinds of rocks settled by itself, and its availability for Portland

cement manufacture on a large scale is rather doubtful. For example, it is doubtful whether it will remain of the composition shown by analysis. The surface, where soundings 25 to 28 were, is less than eight feet above the lake.

The analysis of the marl cited in the prospectus is given in column (1). An analysis by W. M. Courtis of Detroit, is given in column (2), and one by Prof. F. S. Kedzie in column (3).

No. (1) is evidently of a sample of dried marl, and I think that more or less organic matter must have been removed with the water.

No. (2) is of a sample dried at 100° C. and only 42.11% of the original sample.

Analyst.	Prospectus av.?	W. M. Courtis.	F. S. Kedzie.
Silica SiO ₂	1.22	See diff.	9.64
Alumina and iron .....	.61		1.92
Calcium oxide CaO			43.15
as carbonate.....	95.18	83.045	(77.2)
Magnesia.....			1.50
as carbonate.....	2.04	1.201	(3.72)
Sulphuric acid SO ₃		0.485	
Carbon dioxide CO ₂			32.80
Organic matter and water.....	.74	11.700	
Difference.....		3.569	10.99
		100.000	100.00

The character of the deposit is distinctly that of Chara lime and it will be noticed in analysis No. 2 that there is but 32.80% of CO₂, whereas to turn the calcium and magnesium oxides into carbonates 36.27% would be needed, so that probably quite a little of the lime is united either with sulphuric, or more likely an organic (succinic) acid.

The supply of marl is said to be equivalent to 400 acres 20 feet deep. As we could not sound over 13 feet, we have no means of checking the statement exactly. There is certainly a large supply of marl over most of which no stripping will be necessary.

The plan is to dredge the marl, and transport by a lakeside entrance to the factory, and pump out. The plan is to have a rotary pump of the latest design and the cost is figured not to exceed 80 cents per barrel.

The prospectus figures selling price at \$1.40 a barrel, which was probably right then, but later, September, 1901, cement was delivered in Lansing at from \$1.40 to \$1.50 per barrel, and even at times perhaps \$1.25 for new brands, and I am told that it has been sold in

Michigan f. o. b. at factory at 90 cents to \$1.00. Cement advanced, however, during the printing of this report, to over \$2.00.

The prospectus also says that "coal for power can be obtained in abundance within ten miles of the plant." There is very likely some coal at that distance, but hardly an abundant supply.

An analysis by Prof. F. S. Kedzie of an average marl from locations 5, 7, 9, 15, 16, at 8, 6, 3 and 5, 6 and 8 feet, respectively, is given in column (3).

His analysis of the apparently best sample of clay at the south end of the lake, location 28 at eight feet depth, is as follows:

SiO ₂	49.86
(Al ₂ Fe ₂)O ₃	21.22
CaO	6.32
MgO	2.75
CO ₂	5.44
Organic matter and water.....	7.14
Undetermined	7.27
	<hr/>
	100.00

Carbonates are unusually low for a surface clay, which is a good point, but the alumina is high.

Standard Portland Cement Co.

Organized November 15, 1900. Capital \$1,000,000. Office at Detroit.

This company will develop the lime which exists in Zukey and adjacent lakes, at Lakelands, where the Ann Arbor R. R. and the Air Line of the Grand Trunk R. R. cross. Prof. I. C. Russell was employed to test the marl beds, but some time before I made a cursory examination. His report was published,—in part,—in the prospectus.

Referring to the map, Fig. 27, we see a group of lakes, which evidently were once much more continuous, and have been separated by marsh growth, while the 15 to 20-foot bluffs which mark the original borders of the lakes are plain. Zukey Lake was the one which I studied myself more carefully. The west side is lined with a thick and pure bed of bog lime which is capped by a growth of marsh plants and peat, a foot or two thick and coming up to the lake in a perpendicular wall. The marl bed projects out white beneath, and upon it there is Chara, and occasionally dead shells of

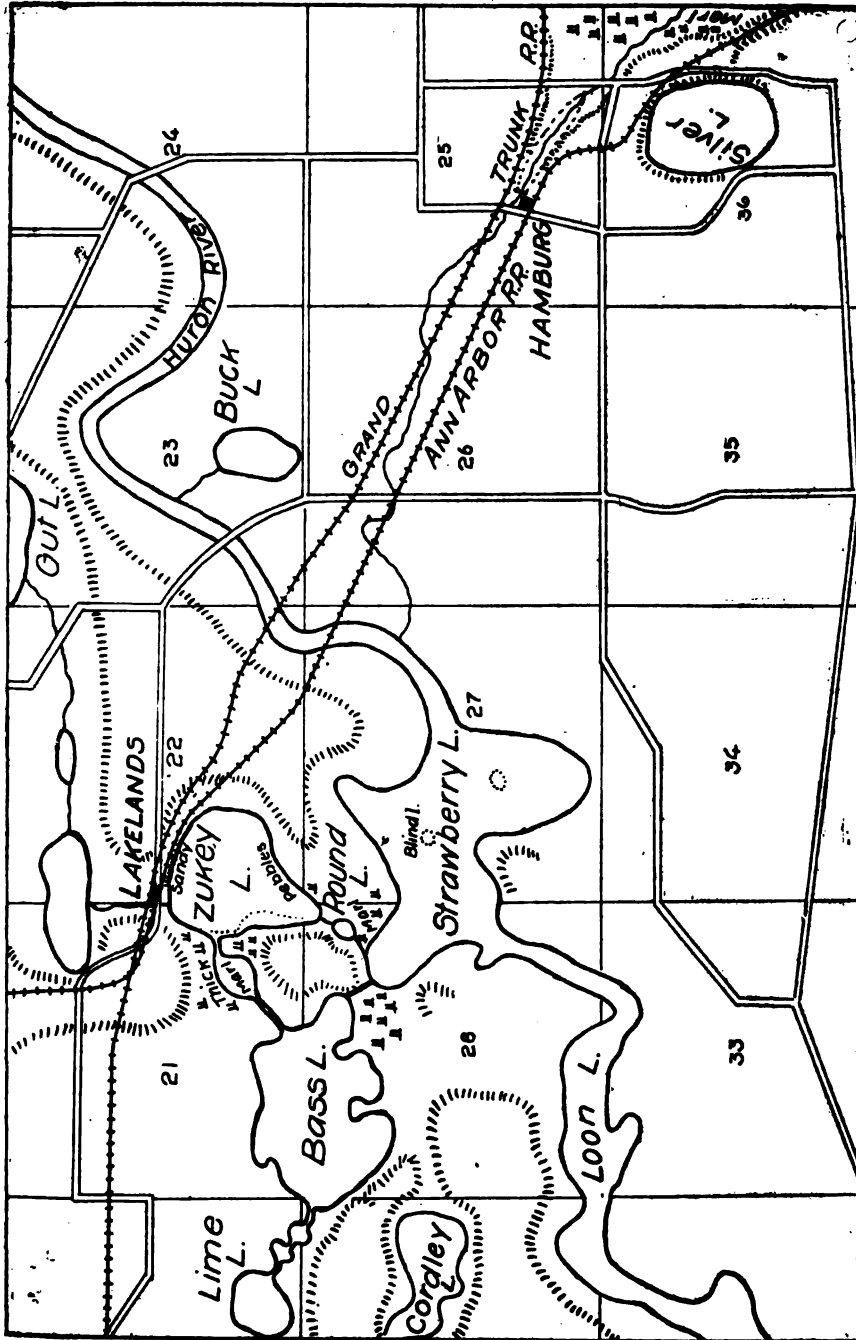


Fig. 27. Lakes near Lakelands, T. 1 N., R. 5 E. Location of Standard Portland Cement Co.

Unio, etc., and twigs are heavily coated with lime. The north part of the lake has a sandy shore and the bluffs are of gravel, and the shells are not so coated. On the southeast side of the lake the marl seems to be covered with pebbles, brown above and green below, which prove, however, to be *Schizothrix* concretions.

The cuts through by the marl bottomed Round Lake to Strawberry Lake are artificial, through a marsh covering a bed of boglime. In Strawberry Lake itself, which is merely an enlargement of Huron River, the lime does not seem to be so continuous. In this lake however, at the place which I have called Blind Island, is an atoll-like formation which is significant of the origin of the lime in general. There is a small, nearly circular area of uniformly shallow water, beneath which is boglime, around the margin of which there is a mat of vegetation of rushes and other aquatic forms, in a ring. Outside the ring the water drops off suddenly to a depth beyond my sounding pole. I should say that the whole region is one of irregular topography, of kames and gravel knolls, and the explanation of this island seems to be that in the original bottom of the lake there was a knoll which rose near enough to the surface of the water to make a good seat for the lime secreting plants, which built up the deposit to near the surface, thereafter building out slowly in all directions on the debris which forms and slides down the slopes, whereupon the other plants came in, but possibly the spring ice has checked the formation of a permanent bog mat of vegetation. If the explanation is correct, they are like the coral islands in origin as well as looks.

The cause of the distribution of the boglime is not altogether clear. It does not seem generally to prefer to run up against a gravel shore, but possibly that may be due to gravel washed down upon it. Silver Lake, for instance, which lies in quite a deep hollow, does not appear to have boglime, while the marshy hollows next east appear to be underlain with it.

This property is said to have been sold to Cincinnati capitalists recently.*

Prof. E. D. Campbell of Ann Arbor tested the materials. The analysis of the raw material "gathered by Prof. Russell during his examination and a composite sample" is No. 1. No. 2 is from Lime Lake, No. 3 from Zukey.

* Detroit Today, 12: 6: 1902.

	No. 1.	No. 2.	No. 3.
Silica .....	.96	1.30	1.30
Ferric oxide .....	.62	.70	.58
Alumina .....	.00		
Calcium carbonate.....	93.92	94.98	94.52
Magnesium oxide.....	1.79	1.44	1.44
Sulphuric anhydride.....	.58	tr.	tr.
Difference, carbon dioxide and organic matter.....	2.13	1.58	2.16
	<hr/> 100.00	<hr/> 100.00	<hr/> 100.00

	Clay.
Sand	3.76
Silica	62.55
Alumina	17.40
Ferric oxide	5.08
Magnesium oxide	1.67
Sulphuric anhydride	tr.
Combined water and organic matter.....	5.55
Calcium oxide.....	2.30
Difference, alkalies, etc.	1.69
	<hr/> 100.00

Wayne Portland Cement Co.

Organized March 18, 1903. Capital \$800,000. Office in Detroit.

Dr. G. Duffield Stewart says that they own 470 acres of marl land within six miles of Brighton on the T. & A. A. R. R.

Pyramid Portland Cement Co.

Organized January 17, 1901. Corporation office at Detroit. Capital \$525,000,000.

This plant is to be located at Spring Arbor, where abundant material is said to be near. It is planned to be a 1,200 barrel a day plant.

The lime deposits here were noted by the Douglas Houghton Survey, and there are exposures of coal measure shales not far off.

An average analysis of the marl is given among Prof. Fall's analyses on p. 352,—and also an analysis of Jackson clay,—a little high in alumina.

German Portland Cement Co.

Organized March 29, 1901. Capital \$300,000.00. Office in Detroit.

This company was organized to develop the beds around White Pigeon, T. 8 S., R. 11 W. They are now building their plant near the village on the Lake Shore road, hoping to be ready by July, 1902.

They expect to use water power for grinding and electricity.

The lime comes from Marl Lake, two miles southeast of the town, which has been described by Mr. Hale on p. 103.

Three Rivers Cement Co.

Organized August 10, 1900. Capital \$20,000.00. Office at Three Rivers, and intended to develop the beds of boglime in that region, at Pleasant and Fisher's Lakes, where it is said to be all over the lakes and 14 feet deep in some places. These plants are geologically in the same region as the already established Branch County plants, and in a general way similarly located, though there are no outcrops of shale clay at hand.

Farwell Portland Cement Co.

Organized June 29, 1901. Capital \$350,000.00; \$10 shares. Bonds \$175,000.00, 6½ twenty-year gold bonds. Officers: J. L. Littlefield, Geo. W. Graham, T. F. Bingham, W. C. Hull, W. C. Fuller.

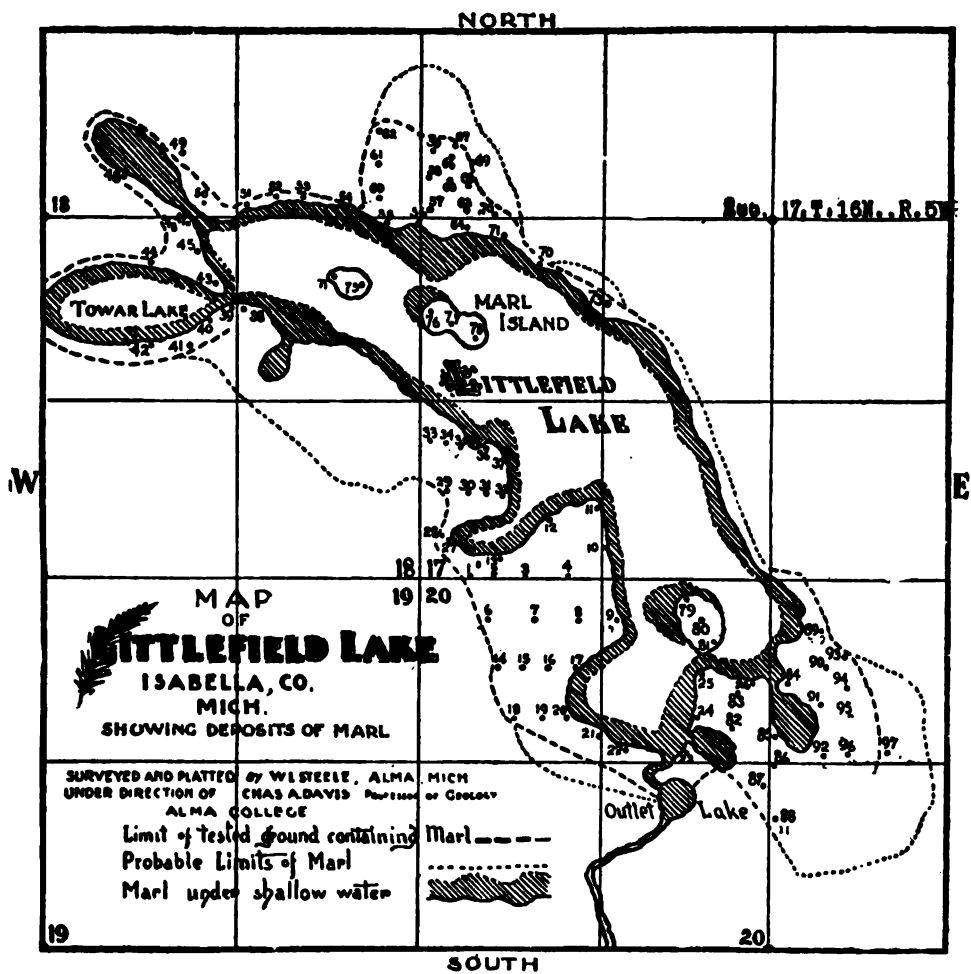
This is the company organized to develop the Littlefield Lake marl deposits, elsewhere described by Prof. C. A. Davis,* and illustrated in Plate XIX. It will be noticed that the marsh covering is rarely as much as three feet, usually from two feet down.

The deposit, while not as accessible as some, is not far from the junction of the Ann Arbor and Pere Marquette systems, which will give good shipping facilities at Farwell, where the plant will be.

The analysis from samples collected by Prof. Davis personally, and analyzed by Prof. F. S. Kedzie, is as follows:

Calcium as oxide.....	51.00	51.67	51.04	51.23
Magnesium as oxide.....	1.75	1.22	1.61	1.20
Carbon dioxide.....	42.94	42.41	42.96	42.80
	<u>95.69</u>	<u>95.30</u>	<u>95.68</u>	<u>95.23</u>
Calcium as carbonate....	91.1	92.2	91.2	91.6
Magnesium as carbonate.	3.67	2.55	3.36	2.50
Shortage of CO ₂.....	.92	.55	1.05	1.13
Insoluble (silica).....	0.31	0.34	0.30	0.63
Iron and al. oxides.....	0.33	0.16	0.24	0.10
Difference (organic)	3.67	3.60	3.65	3.99
Total	100.00			

*Page 92.



PROPERTY OF FARWELL PORTLAND CEMENT COMPANY.



RECORD OF BORINGS.

No. 1 is a mixed sample from the large islands.

No. 2 is from hole 24, unmixed.

No. 3 is a mixed sample from fifteen holes, the northwest half of the lake.

No. 4 is a mixed sample from five holes, the southwest half of the lake.

Farwell is only about 50 miles from the Saginaw coal fields by the Pere Marquette, and the Ann Arbor runs direct to Ohio, in case the clay should be drawn thence, and also passes close to the shale clays around Corunna, already mentioned.

In the Littlefield Lake marl the calcite is in lumps of all sizes, but even when no larger than 0.001 mm. often showing aggregate polarization. I was not able to discover any sharply crystalline grains like those in precipitates.

Clare Portland Cement Co.

Incorporated in New Jersey. Capital \$1,000,000.00, with 100,000 shares.

The company owns 1,905.61 acres of land in Grant and Hatton townships, Clare County, T. 17 and 18 N., R. 4 W.

It is mainly located at Five Lakes, Sections 5, 8, 9 and 16.

The report of the consulting engineer, Prof. R. C. Carpenter, follows. It will be noticed that the clays are the ordinary surface clays with a large amount of carbonates, except one, which is probably only a relatively thin superficial layer in which the lime has been leached out.

A production of 1,000 barrels a day is planned.

The officers are, H. Robinson of Akron, president; C. W. Somers of Cleveland, and the J. H. Somers Coal Co., of St. Charles, vice president; C. W. Perry of Clare, secretary; F. G. Benham of Saginaw, treasurer.

Extract from Prof. Carpenter's report to the Clare Portland Cement Company.

In September last I made an examination of the Portland cement lands owned by W. H. Shepard and partners, of Saginaw, Michigan, and would respectfully report the following results of the examination:

Location.

These lands are located in township 17 north, range 4 west, known as the township of Grant. They comprise altogether 1,905.61 acres, and are principally located in Sections 5, 8, 9, and 16. They

are situated at an average distance of about five miles from the city of Clare, and at a distance of about three and one-half miles from the village of Farwell. The lands are located about one mile from the Harrison branch of the Pere Marquette railroad, and about three miles from the Ann Arbor railroad. No less than five switches for logging railroads were at one time graded through the property, and these grades are now all in good condition for railroad service by simply laying of ties and track. The property is all owned by Mr. W. H. Shepard and partners, who claim to have a perfect title.

The country surrounding this property is a highly developed farming region with a clay loam or clay soil, and is quite rolling in character.

Amount of Cement Material.

The cement material which is found on this tract of land consists of marl and clay of very excellent quality.

The marl is found in the bed of five lakes, where it is covered with water, which varies in depth from a few inches to several feet; it is also found in several swamps which surround the lakes or lie adjacent to them, where it is covered with muck, having a depth which varies from a few inches to one or two feet. The total amount of the marl land as measured by a planimeter from an accurate map submitted, is 754 acres, of which 233 acres are lake and 521 marsh. The average depth of the marl over this entire tract would seem, from such information as I can obtain, which was checked from actual measurement, in a large number of places to exceed twenty feet in depth, but in order to make a safe estimate, I have assumed that it was but fifteen feet in depth. To determine* the amount of Portland cement which could be manufactured from this amount of material, we will consider the following data referring to the composition of Portland cement.

One barrel of Portland cement contains 380 pounds, of which, under usual conditions, 64 per cent would be lime (CaO) and the remainder part clay. Roughly speaking, two-thirds of the Portland cement is lime and one-third clay. The marl is carbonate of lime (CaCO_3). The weight of the carbonate of lime for a given bulk is in excess of that of the lime as 100 is to 56. Calculating from data thus submitted, it will be found that for one barrel of Portland cement would be required 570 pounds of carbonate of lime, which is about the equivalent of marl when perfectly dry. In order to account for impurities of various kinds, and to make the estimate doubly safe, it is assumed that 600 pounds of dry marl will be required for each barrel of cement.

The marl as found at the bottom of the lakes usually contains 70 per cent of water, and that from swamps usually contains 50 per cent of water. This would indicate that for each cubic foot taken from the bottom of the lake would contain 48 pounds and that from the marsh would contain 80 pounds of carbonate of lime.

*Compare calculations on page 38, and pages 167 to 168.

Consequently, it would require for each barrel of cement made, 12.5 cubic feet of lake marl, or 7.5 cubic feet of marsh marl. It is seen from this that the marsh marl is preferable, for the reason that it contains less water, which must be evaporated during the process of manufacture.

One acre equals 43,560 square feet, and if worked fifteen deep would make 93,100 barrels of cement from the marsh marl and 52,150 barrels from the lake marl. The total capacity of the deposit by this calculation would be from the marsh marl 48,505,100, and from the lake marl 12,150,950 barrels, making a total of 60,650,050 barrels. If the deposit were worked at the rate of 1,000 barrels per day for 365 days each year, it would furnish a supply for 166 years.

Clay of very excellent quality, as shown by the analysis accompanying the report, is found in large quantities immediately adjacent to the marl beds. The clay covers an area exceeding 160 acres and has a depth varying from 20 to 60 feet. About one and one-half cubic feet of clay are required per barrel of cement, although when carbonate of lime is mixed with the clay, as is found in this deposit, the amount required will be more, and may average two and one-half cubic feet per barrel. This condition, of course, implies the use of less marl, which is not taken into account in estimating our quantity. Taking the clay as averaging 30 feet in depth, one acre would supply enough for 493,000 barrels. This calculation indicates that the amount of clay available is much in excess of that required to manufacture the marl into Portland cement.

In addition to the clay in the upland adjacent to the marl, an investigation shows that it lies underneath the marl, and consequently the amount available is much in excess of what the calculation indicates.

Roughly speaking, there is enough material to operate a cement plant making a thousand barrels per day, for a period exceeding 166 years.

Character of Cement Material.

An analysis of the dry sample of marl shows as follows:

	No. 1.	No. 2.
Clay, i. e., silica, alumina, iron.....	3.65	2.56
Calcium carbonate.....	94.15	96.04
Magnesium carbonate.....	2.20	1.40

An examination of various samples has as yet shown no free sand. As the surrounding country is largely clay, it is very improbable that any is found in the marl.

An analysis of dried samples of clay shows the following results:

	No. 1. Top of bank	No. 2. About 20 feet down.	No. 3. About 30 feet down.	No. 4 Beneath marl
Silica.....	65.05	47.60	45.60	50.40
Alumina.....	25.00	15.00	15.85	22.10
Iron.....	5.80			
Calcium Carbonate.....	2.05	28.29	28.82	24.00
Magnesium Carbonate.....	0.40	6.00	8.60	0.52
Loss.....	1.64	2.91	3.13	2.96

These analyses differ from each other in the percentage of calcium carbonate present. This is a very desirable addition* to the clay, but for the purpose of comparison, the following table is presented, which is calculated on the basis of no carbonate of lime being present, and magnesia is reduced from carbonate to oxide.

	No. 1.	No. 2.	No. 3.	No. 4.
SiO ₂	67.60	69.45	68.95	69.02
MgO	0.19	4.20	4.65	0.35
Al ₂ O ₃	26.00	21.80	23.35	30.26
Fe ₂ O ₃	6.00			

These clays are all high in silica, which is the most desirable element in the manufacture of Portland cement, and they are low in any elements which are undesirable. In fact, these clays are hardly to be surpassed in chemical composition, and so far as the writer knows, are fully equal to those found in any locality.

In connection with the manufacture of Portland cement experience has shown much more difficulty in securing deposits of good clay than in obtaining carbonate of lime, and most of the difficulties which have been experienced in the manufacture of Portland cement have been due to the fact that the clays obtainable contain less than 50 per cent of silica. As showing the fact that a good cement is made with clay of a similar composition, I submit analysis of the Sandusky clay, used by the Sandusky Cement Company, and the Warner clay, used by the Empire Cement Company, two of the oldest companies using marl and clay, reduced to a similar basis as the table given above.

	Sandusky.	Empire.
SiO ₂	72.2	65.50
Al ₂ O ₃	18.30	33.50
Fe ₂ O ₃	6.65	
MgO	2.08	0.82
	99.23	99.82

*In this statement, Prof. Carpenter differs from the prevailing opinion, as may be noted by comparing statements elsewhere in the report. This is not because the calcium carbonate itself is deleterious, but because as the analyses show it is liable to be very variable, and to be associated with much magnesia, so that it is more difficult to make the cement of a constant composition. L.

I have made in the laboratory of Sibley College, a small quantity of Portland Cement from this material. This was of excellent quality, giving a tensile strength as follows:

Age.	Strength (lbs.)	Remarks.	Age.	Strength (lbs.)	Remarks.
2 days.....	285	Neat.	1 month..	1022	Neat.
"	328	Neat.	1 " ..	1112	Neat.
2 "	375	Neat.	1 " ..	962	Neat.
8 "	868	Neat.	7 days....	240	3 pts. sand.
8 "	860	Neat.	7 "	220	3 pts. sand.
1 month...	1056	Neat.	7 "	212	3 pts. sand.

All samples left one day in air and remainder of time in water.

Watervale Portland Cement Co.

Capital \$1,000,000.00, of which \$600,000 common, \$400,000 preferred, a share of the common being given with every share of the preferred.

The parties interested in this project were also interested in the Omega and Elk Rapids, and apparently are letting it lie dormant, until the latter are better established. The company was said to own 800 acres of marl bed, on the Willow Brook farm and about the Herring Lakes, in Sections 13, 14, 15, 22, 23, 24, T. 25 N., R. 16 W., and Sections 18 and 19, T. 25 N., R. 15 W. The average depth is said to be 20 feet. There is said to be also 60 acres of clay banks three feet deep and over, and 175 acres of other lands with houses, etc.

A feature of this proposition is the nearness to the Great Lakes, so that the lower lake can easily be made a harbor, being from 60 to 80 feet deep, while the upper lake, which is said to be shallow, is said to be underlain by over 25 feet of marl, which also extends beneath the swamps around its margin, where it is covered by not over three feet of vegetable matter.

One reason for the comparative scarcity of marl near the Great Lakes may be that owing to the relatively recent fluctuations of level, there has been not enough time for its accumulation, and it is worth noting that these lakes are close to an axial line of tilting, passing through Port Huron, along which the lake level must have been relatively permanent. The property was reported upon by Lathbury & Spackman, Prof. Delos Fall, and C. B. Stowe.

Lupton Portland Cement Co.

Organized under the laws of New Jersey, January, 1901. Office in Chicago. G. T. Stanley, president; E. A. Worthington, vice pres-

ident and treasurer; W. Higgs, secretary; W. C. Edgar, assistant secretary; A. H. Cederberg, superintendent. Capital \$1,250,000, of which \$600,000 was to be placed on the market, two-thirds at two-thirds of par, the balance at par.

The size of the plant planned may be 1,200 barrels daily output.

The photographs in the prospectus show very well the swampy outbuilt margin to the lakes.

Mr. Stanley is we believe the prime mover in this company, having been engaged in lumbering around Lupton.

Extracts from the report of A. H. Cederberg:

Messrs. Lathbury & Spackman of Philadelphia, have analyzed our marl and clay, and the following is their analysis in full:

Lab. No. 942.—Marl from North Lake No. 1.

Silica (SiO_2).....	.25%	
Alumina and Iron Oxide (Al_2O_3 , Fe_2O_3)..	.19%	
Lime (CaO).....	52.38%	93.53%
Magnesia (MgO).....	1.14%	CaCO_3
Sulphuric Acid (SO_3).....	.18%	
Loss on Ignition.....	46.05%	
	<hr/>	
	100.19	

Lab. No. 943.—Marl from North Lake No. 2.

Silica (SiO_2).....	.24%	
Alumina and Iron Oxide (Al_2O_3 , Fe_2O_3)..	.08%	
Lime (CaO).....	52.97%	94.58%
Magnesia (MgO).....	1.13%	CaCO_3
Sulphuric Acid (SO_3).....	.08%	
Loss on Ignition.....	45.49%	
	<hr/>	
	99.99	

The analyses of marls show them to be very uniform and high in lime, while they are low in injurious ingredients, such as magnesia and sulphuric acid, hence are well adapted to the manufacture of Portland cement.

Lab. No. 957.—Blue Clay No. 2.*

Silica (SiO ₂).....	56.09%	
Alumina & Iron Oxide (Al ₂ O ₃ & Fe ₂ O ₃)..	28.89%	Very
Lime (CaO)	00.00%	little
Magnesia (MgO)	0.58%	Iron
Sulphuric Acid (SO ₃).....	0.41%	Oxide
Loss on ignition.....	7.58%	
	93.55	
Difference (alkalies)	6.45	

This clay is well adapted for the manufacture of Portland cement. A mixture of equal parts of blue clay No. 2, and the Spring Lake clay† would give a clay with a better ratio between the alumina and silica than the blue clay alone; also the percentage of magnesia in this mixture would be low.

The village of Lupton is on the Rose City branch of the Detroit and Mackinac railway, about 27 miles from the Emery Junction. The conditions for a mill site are more than satisfactory. A mill could be erected, as suggested, right on the outskirts of the village of Lupton, or down by the lakes, which are situated about a mile from the village itself.

The marl deposits are, I may say, inexhaustible; and from samples taken, not only by myself, but that have also been forwarded to me from Lupton, and to Messrs. Lathbury & Spackman of Philadelphia, I can state that the marl is superior in its quality to most of the marl beds that have come to my notice. The conditions for getting at this marl are very easy. One of the lakes could be drained at an expense of a few hundred dollars to such an extent that steam shovels would be entirely unnecessary, thus reducing the cost of putting the marl on cars to the mill, to a minimum.

The clay that has been found on the property is not very well adapted to the mixture for first-class Portland cement; but only a few miles away from there another clay deposit is of superior quality, and which clay, I am informed, can be deposited at the mill at a cost of thirty cents per ton. The ratio between marl and clay necessary for a mixture would lie between the figures of four and five to one.

After having made thorough chemical analyses of the raw material, and which analyses correspond entirely to those made by Messrs. Lathbury & Spackman, I went to work and ran through a rotary kiln enough raw material to produce a sufficient quantity of Portland cement, in order to make necessary physical tests. The chemical mixture in the raw was made so as to conform to the standard requirements of Portland cement by the American Society of Civil Engineers, which requirements, as you well know, are

*Apparently a Michigan series shale clay. L.

†A brown clay used to reduce the ratio of alumina which is rather too high.

higher even than those of the United States government. The fineness of the cement produced was satisfactory, the color was pure Portland shade and tensile strength on the briquettes made was as follows:

After 24 hours: 444 and 486 lbs. Average 460 lbs.
(Final set in air and balance in water.)
After 3 days: 618 and 643 lbs. Average 633 lbs.
(1 day in air; 2 days in water.)
After 7 days: 702 and 829 lbs. Average 815½ lbs.
(1 day in air and 6 days in water.)
After 30 days: 891 and 916 lbs. Average 903½ lbs.
(1 day in air, 29 days in water.)

Only the regular methods adopted in cement making were used in the making of these briquettes. The initial setting was 172 minutes; the final setting 360 minutes in all instances. The amount of sulphuric acid in the finished product was 1.53 per cent, thus insuring a cement of superior quality and of which there can be no doubt as to its durability.

In using the above figures, I have taken into consideration the fact that you must produce 1,200 barrels of Portland cement every 24 hours. That means that a plant must be constructed that has a capacity of turning out 1,500 barrels in the same time—24 hours. It may astonish you to hear of this, but it remains as an absolute fact. We very often hear that parties go to work and construct a cement plant of 1,200 barrels capacity, and they will figure in this 1,200 barrels on no repair account whatever. As a result, there are in the United States to day only two mills to my knowledge that have a capacity of standing by the figures agreed upon for a 24 hour output. These two mills are the Lehigh Portland Cement Company's mill "B," at West Coplay, Pennsylvania, and the Whitehall Portland Cement Company's mill at Cement Town, Pennsylvania. It must be very evident to you that if an engineer guarantees to turn out cement at a certain figure, he must rely upon it that his output is never decreased, but if anything, increased during the 24 hour run. We very often hear some engineers that guarantee 200 barrels of clinkers per day in a 60-foot rotary kiln. That guarantee is all nonsense. It is an absolute impossibility. In the first instance, every rotary kiln must stand idle from three to four hours every day, owing to what is in burning practice called "patching." Hence, if a cement mill has got, say for instance, twelve rotary kilns, it means to say that two rotary kilns will practically lie idle during the 24 hours.

Furthermore, patching is not the only cause of shutting down a kiln. The brick lining in a rotary kiln is subjected to an intensely hard wear and tear, and it is nothing unusual to see rotary kilns relined partly every two months. That means another shut down of the rotary kilns for two whole days. In my experience, I have found that it is a safe guarantee to figure on a rotary kiln having an average monthly capacity of 130 barrels of clinkers in 24 hours. So much in the rotary kiln process.

If we go to the grinding process, the conditions there are just the same. A maker of machinery has been invited to figure on an outfit to produce so many barrels. He gives you a figure. You go to another manufacturer and he turns in another figure. The manufacturer that turned in the first figure has probably been a trifle too high. He wants to reduce his first figure in order to obtain the bid, and the first thing he overrates the grinding capacity of the machine he proposes to furnish. Knowing this full well, it is an absolute necessity to have a surplus of grinding capacity in both raw and clinker departments of not less than twenty-five per cent, thus doing away with any danger whatever tending to reduce your 24 hour output and increase the manufactured cost per barrel.

It is also a very noticeable fact that repairs cost as a rule a mere trifle as far as cost is concerned, and that the largest expense in connection with the cement mill is the *shut downs*, thus decreasing the output and increasing the cost to a considerable degree.

Standiford Portland Cement Company.

In the northwest corner of Branch County, not far from Union City but nearer Athens, are some extensive beds of marl which have been investigated for the Standiford Portland Cement Company by Prof. Delos Fall and H. K. Whitney. The results of a thorough survey and a large series of analyses are shown in the map and tables herewith given. Mr. Whitney says that over one thousand soundings of same were taken, 508 on land, 96 on the shore line and 445 on the lakes when covered with ice.

"The bottom of lakes, except at mouths of cracks and in the deepest portions of the line of flow is clear clean marl. At the mouths of creeks and in the deepest portions of Kynion and Lehr Lakes in line of flow it is overlain with sediment as indicated on the large map. It is a soft dark sediment, apparently organic material, or the same mixed with marl and is almost entirely in deep water and outside the estimated 240 acres."

"A large part of the surface material (peat, muck, etc.) on the marl lands could readily be burned off in time of low water. Points when it is four feet deep are in general two feet above ordinary water level; some points four or five feet above. It is, however, quite possible that it might have value for fuel.

"The difference in water level between the lakes (between Lehr and Kynion Lakes, 5 meters between Kynion and Clayton Lakes 1 inch), could be readily eliminated by dredging for marl. On May 9, 1900, Clayton Lake was 2 feet 4½ inches above the river at mouth of outlet from lakes at time of medium high water. At ordinary or low water it would be as much as 3 feet. The distance is 1¼ miles

direct (about $1\frac{3}{4}$ miles on the line of the creek). For about \$1,000 the water in lakes could be lowered about $1\frac{1}{2}$ to 2 feet, with a benefit of about \$1,000 to the adjoining property, aside from marl beds. Then at low water nearly all of the surface material could be burned off from the marl lands, with little trouble and at nominal expense. Similar large marshes in the vicinity have been burned off below the ordinary water level, accidentally or intentionally."

The estimated acreage of marl with an average depth of 20 feet is computed as follows by Mr. Whitney:

	Acres.	Acres.
Area of lakes more than 20 feet deep.....	136	
Area of lakes less than 20 feet deep.....	104	
Total area of lakes	—	240
Area of land 10 feet or more marl, 4 feet or less of surface	90	
Area of land 10 feet or more marl, 4 feet or more surface	52	
10 to 30 feet of marl (average 20 feet).....	142	
5 to 10 feet of marl (average 7 feet).....	33	175
Area of land and water	—	415
Less allowance (possible error).....	—	15
		400

For commercially available marl we shall have, however, within 30 feet of surface:

	Acres.
Area of land, 10 to 30 feet thick, averaging 20 if we neglect thickness above 30 feet	142
Area in lakes to 20 feet of water	104
	246
Less allowance for error	6
Total acreage 20 feet thick	240
The 33 acres of marl between 5 and 10 feet thick would be equivalent to	10
Total	250

Which would be equivalent to over 8,000,000 cubic yards.

Prof. Fall went over the bed and took at proper intervals a series of 84 samples, and the analyses given in the table annexed are of the entire series not omitting any.

SAMPLES from MARL BEDS of the STANDIFORD PORTLAND CEMENT CO.

GITHENS, MICH.

Explanation.—
M = Mush.
P = Peat.
G = Grass, roots, and loose, partly decayed vegetation.
W = Water (in lake).
B = Bottom of Marl (at depth sounded).
+ = No Bottom.
H = Quick Mud (given).
28, H = Hard at 28' below surface.
C = Clayey appearance of bottom.

TABLE showing: Depth of Samples, Depth of Marl, Depth and Kind of Surface Covering, etc., at all points in and Marl Beds from which Samples were taken for Chemical Analysis.

For Location of Same, See Map (Station Nos. corresponding to Sample Nos.)

Samples taken by
Dale F. S. D., Analytical Chemist, Albion, Mich. Harcen K. Whitney, Surveyor, Barre Creek, Mich.

Sample Number	Surface Material	Depth of Sample	Depth of Surface Material	Depth of Clear Marl	Depth of Soundings	Bottom of Marl, etc.	Sample Number	Surface Material	Depth of Sample	Depth of Surface Material	Depth of Clear Marl	Depth of Soundings	Bottom of Marl, etc.
1	1 a	P	1/2	12 1/2	20 1/2	25 B (Bottom of 25)	51	65	P	1/2	16	22 1/2	26 H
2	1 b	-	-	20 1/2	-	-	52	66	G	1	18	23	27 B
3	2 a	G W	1 1/2	10	20 1/2	32 + (No Bottom)	53	67	P	2	15	20	22 B
4	2 b	-	-	20-25	-	-	54	68	P	2 1/2	7	5 1/2	8 B
5	3	P	3	1	20 1/2	23 1/2 B	55	69	W	1 1/2	17	17 1/2	18 B
6	4	G	1	1	29	30 B	56	70	P	3	13	12	15 B
7	5	W	2 1/2	15	29 1/2	32 +	57	71	W	1 1/2	10	24 1/2	26 B
8	6	W	5	14	20	25 B	58	72	P	2	8	18	20 B
9	7	W	4	10	27 1/2	31 1/2 B	59	73	G	1 1/2	18	27 1/2	28 B
10	8 a	G W	1	15	31	32 +	60	74	W	1	16	23	24 B
11	8 b	-	-	23	-	-	61	75	P	3	10	19	16 B
12	9	M P	2	20	22 1/2	24 1/2 B	62	76	W	1 1/2	15	31 1/2	32 +
13	10	M P	5	19	16	21 B	63	77	W	1	15	31	32 +
14	11	M P	6	20	24	30 B	64	78	W	9	10-12	21	30 B
15	12	M P	6 1/2	15	27 1/2	32 +	65	79	P	2	12-15	29 1/2	31 1/2 + (28, H)
16	13	W	1 1/2	20	29	34 B	66	80	P	2	15-17	22 1/2	24 1/2 B
17	14	P	2 1/2	15-20	25 1/2	26 B	67	81	P	2 1/2	7-9	8	10 1/2 B
18	15	W	1	2	22	23 B	68	82	P	3	9-11	9 1/2	12 1/2 B
19	16	W	1	10	20 1/2	25 1/2 B	69	83	W	1	12-17	19	20 B
20	17	P	6	18	28	32 + (30 H)	70	84	W	1 1/2	5-6	8	8 1/2 B
21	18	P	3	20	25	28 B	71	85	W	7	6-20	20	31 +
22	19	P	5	15-16	13	17 B	72	86	W	1	12-15	16 1/2	17 1/2 B
23	20	P	3	20	18	21 B	73	87	P	2	12	17	19 B
24	21	W G	1	15	17	18 B	74	88	W	1	19	30	31 +
25	22	P	1 1/2	15	23	24 1/2 B	75	89	W	2	17	27	29 H (Bottom of)
26	23	W G	1	15-16	22 1/2	23 1/2 B	76	90	W	17	30-31	14	31 + (29, H)
27	24	P	4	10-12	14	18 B	77	91	G	4	1	23	24 B
28	25	W	1	10	24	25 B	78	92	W	1 1/2	14	25	25 1/2 B
29	26	P	3	15	29	32 +	79	93	W	1	11	20	21 B
30	27	P	4	15	28	32 +	80	94	W	10	20	18	28 B
31	28 a	P	2	12	30	32 +	81	95	W	8	18	23	31 + (29, H)
32	28 b	-	-	20	-	-	82	96	W	6	19	20	24 B (26, H)
33	28 c	-	-	32	-	-	83	97	W	2	15	21	23 B
34	29	M	3	5-7	25	28 B	84	98	P	2	12	21	23 B
35	30	M	4	19	19 1/2	23 1/2 B	85	99	G	1 1/2	13	22 1/2	29 B
36	31	G	2 1/2	16	27 1/2	30 B	86	100	W	1 1/2	18	25 1/2	27 B
37	32	P	3	15	15	18 B	87	101	W	1	14	24 1/2	25 1/2 B
38	33	W	1	2	27	28 B	88	102	P	5	10		1
39	34	P	3 1/2	12	11 1/2	15 B							
40	35 a	P	2 1/2	10	15	17 1/2 B							
41	35 b	-	-	16 1/2	-	- (Sample, C)							
42	36	W	1	8-6	28	29 B							
43	37	P	4	10	17	21 B							
44	38	P	5	16	25	30 H							
45	39	M	6	10	21	27 B							
46	40	P	3	10	24	29 H							
47	41	W	0	4	21 1/2	21 1/2 B							
48	42	P	5	8	4	9 B							
49	43	W	1/2	11	20	20 1/2 B							
50	44	P	3	18	19	22 B							

1 a, and 1 b, both taken at Station 1 (See Map).

28 a, 28 b, 28 c, all taken at 28'.

28 sounded 33 ft. with water was on ft. high.

H. K. Whitney, Surveyor.

Fig. 28. Table of data relative to the samples, the analyses of which are given on subsequent pages. The numbers in the second column correspond to the Roman numerals in the second columns of Figs. 29 and 30. Soundings of Standiford Portland Cement Company on Kynion, Lehr and Clayter lakes, Sections 4, 5, 8, 9, 16 and 17, T. 5 S., R. 8 W.

Analyses of Kynion, Lehr, and Clayton Lake Marls, T. 5 S., R. 8 W., by Delos Fall Ph.D. at the McMillan Chemical Laboratory, Albion								
Lab. Number	Field Mark	SiO ₂	Fe ₂ O ₃ Al ₂ O ₃	CaCO ₃	MgCO ₃	SO ₃	Organic Matter	Depth in feet
500	IA	.63	.998	88.73	20	none	9.45	
501	IB	.72	.72	88.85	23	none	11.71	
502	IIA	1.16	3.06	89.05	.37	none	6.36	
503	IIIB	1.91	4.83 ^a	85.58	none	none	7.68	
504	IV	3.78	5.19 ^a	82.97	none	none	8.06	
505	V	3.78	4.29 ^a	80.48	none	none	11.45	
506	VI	2.99	1.91	79.86	none	none	11.44	
507	VII	2.01	4.11	81.43	trace	none	12.45	
508	VIII	.65	2.40 ^a	88.55	none	none	7.40	
508B	VIII B	1.60	4.05	84.75	trace	.37	9.23	
509	IX	.73	2.00	77.60	trace	1.54	18.13	
510	X	3.52	2.71	93.76	trace		none	
511	XI	3.81	2.18 ^a	91.86	trace	none	2.15	
512	XII	4.74	1.00	83.22	1.50	.74	8.80	
513	XIII	2.98	1.60	88.03	none	.55	6.01	
514	XIV	1.89	3.43	90.27	trace	none	4.41	
515	XV	2.20	4.15	88.49	trace	none	5.17	
516	XVI	5.98	2.14	86.89	trace	none	2.58	
517	XVII	2.68	3.26	85.15	none	none	8.91	
518	XVIII	2.64	3.73	89.71	none	none	3.92	
519	XIX	3.25	3.55	85.57	[merest] [trace]	.38	5.25	
520	XX	2.10	7.25	88.36	[merest] [trace]	2.43 ¹	14	
521	XXI	1.21	2.00	89.83	trace	.76	4.26	
522	XXII	1.17	3.87	91.38	trace	none	3.14	
523	XXIII	1.15	.77	91.57	trace	1.25	3.38	
524	XXIV	3.18	1.55	90.61	[merest] [trace]	1.79	2.93	
525	XXV	1.38	.71	91.97	.11	.90	2.73	surface
526	XXVI	2.18	1.14	91.15	.42	1.19	3.06	
527	XXVII	3.62	5.21	87.03	[merest] [trace]	.39	3.92	
528	XXVIII	3.34	4.83	90.10	trace	none	1.73	12
528B	XXVIII B	4.84	5.74	85.42	trace	none	4.00	20
528C	XXVIII C	7.47	7.37	82.89	.25	none	2.02	32
529	XXIX	2.11	5.13	87.41	2.11	none	5.35	5-7
530	XXX	.65	1.27	92.83	trace	.27	5.25	18-20
531	XXXI	1.11	1.38	93.95	.18	.19	3.19	
532	XXXII	8.34	5.22	83.26	trace	1.34	1.48	
533	XXXIII	1.56	1.36	93.20	trace	.86	3.22	
534	XXXIV	2.82	2.93	92.67	none	1.34	1.13	
535	XXXV	6.92 ^c	3.11	85.53	none	.88	3.78	
536	XXXVI	1.08	1.15	91.11	trace	1.04	5.62	
537	XXXVII	.88	1.70	91.51	2.01	1.38	2.52	
538	XXXVIII	2.15	2.13 ^a	90.84	trace	.45	4.43	

ATHENS, MICH.

[unclear]

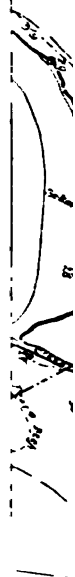


Fig. 29. Analyses of the Standiford P. C. Co. marl by Delos Fall. See Fig. 28.

Analyses of Kynion, Lehr, and Clayton Lake Marls, T. 5 S., R. 8 W., by De los Fall Ph.D. at the McMillan Chemical Laboratory, Albion.								
Lab Number	Field Mark	SiO ₂	Fe ₂ O ₃ Al ₂ O ₃	CaCO ₃	MgCO ₃	SO ₃	Organic Matter	Depth in Feet
539	XXXX	2.30	2.78	90.83	.30	1.77	3.02	
540	XL	1.20	2.80	88.82	trace	1.26	5.92	
541	XL I	.53	.71	92.29	trace	.55	5.92	
542	XL II	1.78	.96	93.98	trace	.54	2.74	
543	XL III	.27	.77	91.40	1.33	.51	5.72	
544	XL IV	.68	1.18	91.85	2.00	1.70	2.59	
545	XL V	2.10	1.04	90.21	trace	.63	6.02	
546	XL VI	.47	.90	88.82	1.44	.97	5.35	
547	XL VII	2.05	2.65 ^a	87.33	trace	.32	7.65	
548	XL VIII	5.59	2.65	82.03	trace	.37	9.36	
549	XL IX	1.43	1.87	89.49	2.41	1.09	3.71	
550	L	1.12	1.21	89.39	.39	.67	7.22	
551	L I	.45	1.43	89.60	1.77	.74	6.03	
552	L II	11.45	4.83	77.94	trace	2.28	1.72	
553	L III	.60	.97	90.84	1.39	.70	4.78	
554	L IV	.58	1.24	90.50	1.13	.87	5.69	
555	L V	20.63 ^b	3.41	68.02	1.71	2.18	3.80	
556	L VI	.57	1.27	91.47	trace	.72	3.29	
557	L VII	1.27	1.10	89.33	1.39	.61	3.96	
558	L VIII	1.23	.90	87.06	trace	.69	9.72	
559	L IX	2.93	4.22	87.06	.3	.79	4.70	
560	L X	2.20	2.32	90.01	.5	.73	4.24	
561	L XI	4.81	2.42	88.44	trace	none	2.33	
562	L XII	3.97	2.60	86.25	1.50	.91	4.77	
563	L XIII	2.30	2.95 ^a	87.88	trace	1.13	5.74	
564	L XIV	3.74	2.85 ^a	87.33	none	1.22	4.86	
565	L XV	2.38	2.36	81.25	none	.70	13.31	
566	L XVI	6.21	2.00 2.46	85.68	trace	.79	2.86	
567	L XVII	3.54	1.80	91.19	trace	.52	2.95	
569	L XIX	2.00	3.03 ^a	82.58	trace	.73	11.66	
571	L XXI	6.16	.81	88.52	trace	.50	4.25	
572	L XXII	1.17	1.36	92.24	.5	.67	4.06	
573	L XXIII	1.30	.99	91.21	trace	none	6.50	
574	L XXIV	1.39	1.91 .71	93.15	none	1.44	2.6	
575	L XXV	1.25	1.85 ^a	90.42	none	.19	6.29	
576	L XXVI	1.75	2.85 ^a	90.65	trace	.71	4.04	
577	L XXVII	2.71	2.49 4.27	85.68	.30	.61	3.69	
579	L XXIX	2.50	2.48	90.54	trace	.8	2.50	
580	L XXX	4.42	1.04	88.83	trace	.89	4.82	
581	L XXXI	1.55	.93	92.89	trace	.34	4.29	
582	L XXXII	.91	1.73	87.33	trace	.52	9.51	
583	L XXXIII	1.91	3.61	90.10	none	1.19	3.19	

a - Trace of iron
b - Sandy.

Fig. 29. Analyses of Fig. 28 continued; where ever in column 4, there are two sets of figures, the upper is for the total iron and alumina, the lower the alumina alone.

The material in every case was dried at 100 C. to expel moisture and sampled. The tables give the amount of each substance found in 100 parts of the dried samples. The samples were taken with apparatus especially prepared for the purpose by which it was possible to know accurately the depth from which the samples came. The average analysis is given among the other analyses by Prof. Fall, page 352, and "exclusive of organic matter the carbonate of lime in these eighty-four samples would average 93.10%, a showing which is remarkably high when it is taken into account the nearly five per cent of clay which the marl contains."

The marl is also very finely and evenly divided.

One peculiarity of this bed to which he calls attention is that a small percentage of clay, ranging from two to six per cent, is found as an admixture with the marl. This of course would be no detriment to the quality of the cement, for as he remarks, the percentage of magnesia and sulphuric acid are insignificant.

Bellaire Portland Cement Co.

This company has been but recently organized to operate near Bellaire, Antrim County. The conditions will be not unlike those at Elk Rapids. It is, I presume, a successor of the Lake Shore company.

West German Portland Cement Co.

Articles filed at Ann Arbor Aug. 13, 1902. Capital \$1,000,000, half preferred. Object to manufacture cement, coke and peat in Lima Township. Linus E. Leach of Detroit appears to be chief stockholder. The marl beds are around Four Mile Lake.

Locations reported by Douglas Houghton Survey.

The first geological survey of the State back in the forties, paid considerable attention to the location of marl, not, however, for its value for cement, but as a fertilizer, though at that time it was also extensively used for making quick-lime. A brief summary of the locations which they noticed, should be given here, since the reports in question are not only out of print, but not easy to obtain second-hand. I have added foot-notes calling attention to the fact, when the locations have since been utilized.

That marls were generally attributed to shells may be indicated by the fact that the symbols used on the maps to denote the location of marls was a small figure of a shell.

First Annual Report, 1838, H. D. No. 4, pp. 276-317, No. 14, pp. 1-39, p. 13 or 287, description of Chara deposits near Grand Rapids.

in Saline Springs; p. 34 or 306, northern part of St. Joseph,* Monroe near Monroe,† and Jackson County.‡

Second Annual Report, 1839, H. D. No. 23,

p. 393, White River.

p. 451,

p. 464, Sec. 15, T. 1 N., R. 1 W.

33 Leslie township.§

35, T, 2 N., R.1 W.

p. 479, Sections 2, 4, 5, 8, 22, 27, Plymouth Township, Oakland County.

Sec. 9, Canton.

495, Monroe, Sections 7 and 9, T. 6 S., R 9 E.

From Third Annual Report of State Geologist, p. 94 of the separate edition.

MARL OR BOG LIME AND TUFA.

"That variety of the mineral which is here designated by the name of marl, is chiefly a carbonate of lime, or lime combined with carbonic acid. It is frequently argillaceous, and mixed with earthy and carbonaceous matters. Throughout the counties enumerated, this mineral is found only in the gravels, sands and clays which overlie the rocks, and may be defined as an alluvial deposit from the waters which have percolated soils charged with lime. On reaching the surface, the water parts with a portion of its carbonic acid, and becomes no longer capable of holding lime in solution, which is then deposited in the form of a pulverulent, chalky substance, in the beds of lakes or beneath the peat marshes.

"As carbonate of lime is a constituent of the covering of molluscous animals, these circumstances are favorable to the collection of great numbers of shells, so that these not unfrequently constitute even the main portion of the bed itself, which may then receive the name of 'shell marl.'

"That form of lime which is called tufa, has a similar origin. It differs in external character, being hard, light and porous, and is that which is familiarly known as 'honey-comb lime.' This characteristic difference is the result of circumstances, not of composition. Tufa is formed in situations which allow access of air, when a strong union of the particles takes place. Marl being always deposited under water, or beneath the peat of bogs, the surrounding

*See p. 312. †See p. 312. ‡See pp. 291, 309, 315.
§See p. 316.

fluid prevents cohesion. This condition is that which is very commonly designated as bog lime."

p. 95. "Thus, according to circumstances, we find a variety of forms assumed by these deposits, from a 'tufaceous marl,' in which the particles have but partially cohered, to a hard 'tufa' or travertine rock, appearing as ledges in exposed hillsides.

"All these recent fresh water limes exist in great abundance in most of the counties enumerated, as well as throughout the interior of the State. In the northern part of Hillsdale,* and the counties of Washtenaw and Oakland, in particular, so extensive and universally distributed are the beds of this useful mineral, that an attempt to ascertain and enumerate all the places in which it exists, is unnecessary, if not impossible.

"But notwithstanding its wide distribution, the uses, and even the existence of this mineral are so little known or heeded, even by those who have most reason to appreciate its value, that I shall adventure some remarks upon its application to practical purposes, and the method of ascertaining its presence.

"For making quicklime, the value of marl and tufa is already appreciated in those parts of our State which, like the counties under review, are nearly destitute of lime rock. Consequently these have supplied the deficiency, and been applied to all the purposes of the best rock lime. Though somewhat inferior in strength, the lime thus obtained is even preferred for particular purposes. It is said, for instance, to be preferable as a wash, owing to its superior whiteness. Its real value is frequently underrated from its not being sufficiently burned; marl being erroneously supposed to require a less degree of heat than limestone.

"Some of the largest deposits of tufa I have met with are formed along the banks of the Huron Valley, between Ypsilanti and Dexter, at several of which, large quantities of lime are manufactured.

"The circumstances which may give rise to the formation of either tufa or shell-marl, where the same source of supply exists, are hereby exemplified. Ledges of tufa occupy the elevated sides of the valley, while copious springs discharging from its foot, occasion a peat morass between it and the river, beneath which is a body of soft marl several feet in thickness.

"Impressions of leaves and branches of trees, and even bones of animals, are numerous in some portions of the tufa, these substances have evidently served as nuclei around which the particles of lime were deposited from the water of the springs, thus both giving an interesting character to the bed and illustrating its formation."

p. 98. "After this recommendation of marl, it may be expected that I advise under what circumstances to look for it. Marl is frequently to be recognized by its light ash color, about the margin and occupying the shallows of lakes. In general, the marl which is most obtainable, will be found to be overlaid by peat or muck of the marshes, often at a depth of several feet. Sometimes its presence, under these circumstances, is indicated by a slight coat-

*Location of Omega plant.

ing of lime visible upon the vegetation on the surface. The growth of the marl bed often causes the overlying bog to swell up into a protuberant form. But such indications are not always visible, and then trial may be made by thrusting down a pole or rod through the peat, when sufficient of the marl, if there be any, will adhere, usually, to make known its presence.

"Every farmer ought to examine well his marshes with this view, and if there is any reason to believe that marl exists there, to test the question fully by digging.

"It may be advisable to raise the marl in the fall and subject it to the action of the winter's frost, in order to bring it to a pulverized state previous to use upon land."

p. 55. "Marl, which is more universally distributed than any other of the calcareous manures of this district, and which will, in consequence of this fact, admit of a universal application, is in itself more valuable for this purpose than limestone, since it generally contains vegetable and animal matter in combination, and its effects are more immediate. It exists in a state of minute subdivision, and is in a condition prepared to become directly a constituent of the soil, while it is necessary that limestone, as well as gypsum, should first be reduced to powder."

Marl.

"Deposits of marl were found in nearly every town in the counties under consideration, occurring in beds and banks of lakes and streams, in marshes, as well as occasionally, on the more elevated and dry lands, at a considerable distance from water.

"This latter position is not unfrequent, but marls found in this situation, invariably show that they occupy what has heretofore been the bed of some lake or pool. Thus the marl does not seem to be confined to any particular soil or geological position.

"For further particulars, respecting the origin and formation of marl, I refer you to Mr. Hubbard's report."

Local Details of Marl. Jackson County.

"Shell-marl occurs more or less abundantly in the town of Napoleon, on Sections 12, 14, 15, and 19, and other deposits of minor importance were also noticed in this town.

"In the town of *Columbus*, marl occurs, forming very extensive deposits in the vicinity of Clark's Lake. It also occurs abundantly on Sections 8, 9, 13, 19, 28, and 29, in the same town. Several of these deposits have an area of more than one hundred acres.*

"Several very extensive beds of marl were noticed in the (P. 56) town of *Liberty*, on Sections 11, 13, 23, 24, and 27, as well as in the bed of Powell's Lake and its vicinity.

*These deposits are not far from the Peninsular plant.

"The town of *Spring Arbor* abounds in extensive beds of marl, which were more particularly noticed on Sections 21, 28, and 29.*

"*Hanover*.—A bed of marl having an area of more than one hundred acres, was noticed, forming a portion of the bed and banks of Farwell's Lake. Inexhaustible deposits of shell and tufaceous marl occur near a lake which forms the head of Kalamazoo River.†

"Town of *Sandstone*.—Marl is not unfrequently met with in making excavations in the marshes in this town. It was noticed near the village of Barry, and also on the farm of Hon. Mr. Gridley.

"*Pulaski*.—Marl occurs in abundance in many of the lakes and marshes of this town. A very extensive bed of shell and tufaceous marl was noticed on the farm of Isaac N. Swain, Sec. 2, occupying an area of more than 60 acres, and having a thickness exceeding six feet. An extensive bed was also noticed on Section 25.

"*Rives*.—A somewhat extensive deposit of marl occurs on Section 9.

"*Leoni*.—Marl, in inexhaustible quantities, occurs near the outlet of Wolf Lake, and also upon Sections 4, 11, 12, 22, and 23.

"Town of *Jackson*.—Marl occurs in this town, in abundance, on Sections 20, 21, 26, 27, and 31 (town 3 south, range 7 west), and also on Section 31 (town 2 south, range 1 west).

"*Concord*.—Several extensive beds of marl occur in this town which were more particularly examined on Sections 8 and 9. Also in the bed and banks of the Kalamazoo River.

"*Grass Lake*.—On Sections 13 and 29,‡ in this town, extensive beds of shell-marl were examined.

"*Springport*.—An extensive bed of marl occurs on Section 15.

"*Tompkins*.—An extensive bed of shell-marl was examined on Section 17, in this town."

Eaton County.

p. 57. "*Kalamo*.—Several very extensive beds of marl were observed on Sections 22 and 25 (town 2 north, range 6 west), and on Sections 19 (range 5 west)."

Kalamazoo County.

"*Texas*.—Shell and tufaceous marl occur in beds of several lakes in this town. Also on Sections 31 and 32 of the same town, is an extensive deposit of this mineral.

"*Alamo*.—On Sections 1, 9, 12, and 24, extensive beds of marl were examined.

"*Cooper*.—Marl is not unfrequently met with in the alluvial lands in the vicinity of the Kalamazoo River.

"*Ross*.—Marl was noticed in several of the lakes and marshes of this town.

*This is the location of the Pyramid Portland Cement Co.; the Peerless have recently bought beds here.

†These deposits are not far from the Omega plant.

‡Location of the Zenith plant.

"*Kalamazoo*.—Tufaceous and shell-marls occur in a large marsh and in the valley of a small stream northwest from the village of Kalamazoo.*

"*Chester*.—Extensive deposits of marl abound in this town, on Sections 4, 9, 10, 11, 12, and 24."

Calhoun County.

"Marl occurs at intervals† through this county in the alluvial lands of the Kalamazoo River, and pebbles and boulders are not unfrequently seen in the bed of the stream, incrustated with a thick coat of tufaceous marl.

"*Milton*.—Marl was observed in this town on the farm of Hon. S. McCamly. It also occurs in several of the small lakes and streams.

"*Marengo*.—Marl is not of very frequent occurrence in this town. An extensive bed was observed on Sections 1 and 2.

"Marl was observed in the town of *Marshall*, near the Hon. Mr. Pierce's mills. Also, in comparatively small quantity, in the lowlands between the village of Marshall and the Kalamazoo River."

Kent County.

p. 58. "Town 6 North, Range 2 West. Tufa occurs in this township in the bed of the Flat River, on Section 26, in a very extensive deposit.‡

"Marl was observed on Sections 3 and 8, Township 6 north, Range 12 west.

"Extensive deposits of shell-marl occur on Sections 22 and 23, township 7 north, range 10 west.

"Marl was examined in township 8 north, range 11 west, on Sections 13 and 14, in a dry burr oak plain."

Ionia County.

"Tufaceous‡ marl occurs in inexhaustible quantities in the vicinity of Lyon, town, Maple P. O. Incrustated in some portions of the tufa, are quantities of leaves, recent shells, and in one instance have been found the vertebra and other remains of a large snake.

"Marl occurs on Section 1, township 6 north, range 5 west; its extent unknown.

"Extensive beds of shell and tufaceous marl exist near Mr. Dexter's mill in the village of Ionia. Also, in the bed and banks of several of the small streams west of Ionia village.

"Extensive beds of marl occur on Sections 10, 11 and 22, township 8 north, range 8 west.

"This abstract of the locations of this valuable mineral only includes some of the most extensive deposits. It is sufficient, how-

*Probably the site of the original Portland cement plant.

†Six places are noted on the map issued by the Douglass Houghton Survey.

‡This is tufa and not the bog lime desired by cement plants.

ever, to render it apparent that marl is distributed in sufficient abundance to afford a ready supply for use as a manure, as also for the manufacture of quick lime. It is within the reach of every man to obtain this restorative for his soils or a lime for economical purposes; an article of which otherwise much of the country would be nearly destitute."

p. 73 (Report of C. C. Douglass).

The great profusion in which the deposit is distributed through the counties of VanBuren, Allegan, and Ottawa, is deemed a sufficient reason for noticing a few of the most extensive deposits.

On Sections 20 and 21, half a mile northeast from Mr. Newell's steam mill, on Maskego Lake, is a very extensive deposit of shell-marl that may be profitably used as a manure on the sandy lands of that vicinity.

Extensive deposits of shell and tufaceous marl occur in the valley of the Kalamazoo River, on Sections 9, 10, 16 and 17, township 3 north, range 15 west, of more than one hundred acres. Also on Sections 16 and 17, township 4 north, range 16 west, there is a deposit of shell and tufaceous marl occupying the area of more than seventy-five acres.

A very extensive deposit of marl was examined on Sections 16 and 17, township 3 north, range 13 west. Some of the portions of this marl are found to contain too much iron ore to make good quick-lime. Care should therefore be had in selecting that portion of the marl which is free from this mineral.

On Sections 13 and 14, township 2 south, range 13 west, marl of a good quality occurs.

Fourth Annual Report, 1841, p. 104, marl and peat, p. 122, marl and peat.

The remaining references to minor, or at least not extensively exploited deposits, will be arranged according to counties, proceeding east and north from Monroe County.

Locations arranged by counties.

1. (68) *Monroe County*.—The marl deposits referred to by the Douglass Houghton Survey above have been also described by Sherzer in his recent report on the county.* He lists: Claim 422, the largest; claim 161; claim 520 (?); S. E. quarter of Sec. 24,* Summerfield; Sec. 7 of Exeter; Sec. 9 of Ash; Sec. 9 of London.

A good sample of marl taken from along the line of the Detroit and Lima Northern was sent in by C. A. Chambers, in September, 1898.

2. (67) *Lenawee County*.—Marl has been reported two miles from Britton, Deerfield township, which is probably calcareous clay and not bog lime.

*Vol. VII, Part I, p. 200. "No large beds of this substance are known to occur."

In the extreme northwest corner we have the Peninsular plant, and there is a good deal of bog lime in this region, e. g., Lowe's Lake, T. 5 S., R. 3 E.

3. (66) *Hillsdale County*.—Besides the deposits of the Omega plant there is said to be a bed of bog lime 11 to 28 feet thick at Nettle Lake, just south of Camden. It is said to have been examined by Mr. Hunter of Philadelphia.

Another bed is near Reading. It belongs to the Monolith Portland Cement Co., whose officers are L. McCoy of Battle Creek, president; M. H. Lane of Kalamazoo and I. P. Baldwin, vice-presidents; H. T. Harvey of Battle Creek, secretary; G. B. Tompkins of Sturgis is treasurer.

Another deposit is at Sand Lake, three and one-half miles west of Hillsdale, Sec. 1, T. 6 S., R. 3 W.

4. (65) *Branch County*.—The plants of this county have already been described by Mr. Hale, and in connection with factories. The county is very rich in bog lime. See the descriptions of the plants at, and visits to, Quincy, Coldwater, Bronson, Union City.

Still other factories are planned at Helmer on the Fort Wayne branch of the L. S. & M. S. R. R. and just west of Coldwater on the river.

5. (64) *St. Joseph County*.—Marl beds near Sturgis have been tested by the same people interested in Bristol and Turkey Lakes, Indiana.

6. (63) *Cass County*.—Near Vandalia at Donald's Lake, Sections 31 and 32, T. 6 S., R. 1 W, is said to be a large deposit, in some places over 25 feet deep.

Near Dowagiac, just north of town, in the lowlands of this old glacial drainage valley, is bog lime. It is said that there are 600 acres, running from 18 to 28 feet in depth, with a percentage of from 75 to 84% calcium carbonate.

Near Niles, beside the bed described by Mr. Hale,* on the farm of R. A. Walton, within half a mile of the C. C. C. and St. L. R. R. is said to be a large bed of marl of excellent quality, along a small stream. Marl was also found with mastodon bones near here.

Harwood Lake on the St. Joseph county line, about 10 miles from Constantine, is said to be surrounded by bog lime. The circumference is about 2 miles and the depth in one place over 50 feet. The owner is W. W. Harvey of Constantine. He also owns a 200 acre bed near Bair Lake, Sec. 5, T. 6 S., R. 13 W.

*Page 107.

7. (62) *Berrien County*.—As mentioned on p. 154 by Mr. Hale, bog lime occurs in the marshes near Benton Harbor.

8. (61) *Van Buren County*.—There is marl in Secs. 13 and 14, T. 2 S., R. 13 W.

9. (60) *Kalamazoo County*.—This is the county where cement was first manufactured, as already described by Mr. Hale,* and Kalamazoo has been quite a headquarters for such enterprises. (Indiana Portland Cement Company, Kalamazoo Portland Cement Company.) Beside the old site and the Hope township regions described by Mr. Hale there are:

Sugar Loaf Lake, southeast of Schoolcraft, T. 4 S., R. 12 W.

Mud Lake north of Schoolcraft.

Vicksburg, T. 4 S., R. 11 W. Around Vicksburg in Kalamazoo County there are lakes with abundant marl, and directly west is a shaking bog (bog lime) where the Grand Trunk has had much difficulty in maintaining grade. The neighborhood is heavily covered with drift with a good deal of sand.

Near Climax, "100 acres with 20 feet of marl."

10. (59) *Calhoun County*.—Homer Lake on the farm of H. O. Cook, and under the lake and under 120 acres of the marsh is bog lime varying from 10 to 30 feet in depth. This bed lies west of the town, and there is said to be a bed of greater area around Kessler's Lakes north of town.

As mentioned in the early reports there are also marl beds of size in Eckford township.

Near the north line of the county, close to Bellevue at Mud Lake are large deposits. See Eaton County. Also in Convis township, on Kinyon Lake (the Creed farm), is a bed.

On the Torrey farm one and one-half miles west of Albion is a small bed of marl, said to be about 25 acres, at the center over 17 feet deep, and shallowing gradually to the edges, and covered by a foot or two of earth (muck). This is an ideal of a complete and as Mr. Hale calls it sealed bed.

The analysis by W. H. Simmons was as follows:

Silica	00.76	00.82
Iron and Aluminum oxides.....	1.71	1.86
Calcium as carbonate	87.57	95.18
Magnesia	no trace.	
Sulphurous anhydride .....	.20	.22
Organic matter	7.91	
Difference	1.85	1.92
Total	100.00	100.00

It is suggested that this was taken so near the surface as to contain an unusual amount of organic matter. The second set of figures is referred to marl free from organic matter.

11. (58) *Jackson County*.—There is said to be a bed, 2.5 feet thick, of white marl underlain by one of blue marl, on the farm of J. Dooley and neighbors, almost a mile long, about six miles northeast of Albion.

The bed in Rives township mentioned by the early survey is extensive, and has recently been tested somewhat.

The Michigan Portland Cement Co., a forerunner of the Wolverine is said to have contracted for about 4,000 acres around Portage Lake, which lies in an old glacial drainage channel, surrounded by extensive swamps, and to have planned a private railroad striking the Michigan Central at Munith.

A bed of bog lime is reported near Kelley's Corners. Also four miles from Jackson.

12. (57) *Washtenaw County*.—Four-mile Lake, between Chelsea and Dexter, on the line between T. 1 and 2 S., and in Range 4 E. is surrounded by bog lime. It is said to average 36 feet deep of bog lime, 96% calcium carbonate. About 1,000 acres are said to have been secured, \$20,000 having been paid for 200 acres of land.

Marl is also reported from Mill Lake, J. H. Runciman, owner.

Near Ypsilanti is said to be a bed of 75 acres, 12 feet thick, under 2 feet of stripping.

On Sec. 12, T. 2 S., R. 6 E., is a small bed of 25 acres and others similar near by. Such beds are very common.

13. (56) *Wayne County*.—Wayne County is not likely to contain much bog lime except perhaps in the extreme northwest corner.

14. (55) *Macomb County*.—The same remarks apply to Macomb County.

15. (54) *Oakland County*.—This county being high, and early uncovered by the ice, and full of old lines of glacial drainage, and deep holes occupied by glacial lakes, probably contains much bog lime,—more than has been reported.

W. A. Brotherton says that there is marl 40 feet above the stream on Stony Creek, near Rochester. Large deposits are reported near Clarkston.

I. J. Hiller is said to have a bed of 75 to 100 acres.

A small bed of 20 acres and 6 feet deep is reported at Bloomfield Center, with others near by.

The beds near Holly have already been referred to in connection with the Egyptian P. C. Co.

16. (53) *Livingston County*.—Near Brighton and only a mile from the R. R. are marl beds of about 100 acres and average depth of about 12 feet. Lime Lake, Sec. 36, T. 2 N., R. 5 E.

West of South Lyon in Green Oak township are also some bog lime deposits.

Two miles north of Oak Grove is a bed of bog lime, on land belonging to Pierce Elwell and others, on the line of the Ann Arbor R. R. There are other beds on the Ann Arbor line north of Howell.

The deposits around Hamburg and Lakelands, have been mentioned in connection with the Standard Portland Cement Co. There are said to be over 1,600 acres of land underlain by bog lime, which in places is 60 feet deep.

17. (52) *Ingham County*.—There are beds of bog lime near Leslie, one located by H. C. Barden.

Analysis of a Leslie marl is as follows:

Silica and alumina, oxides.....	2.60
Ferric oxide	2.25
Calcium as carbonate.....	72.20
Magnesium as carbonate.....	.85
Organic matter	12.
Water	10.
Total	99.90

There is also a small bed covering about 15 acres, in the north-west quarter of Sec. 24, Vevay, T. 2 N., R. 1 W., belonging to Chester Dolbee. It is now cut through by a stream. On the north side Mr. W. F. Cooper found 6 inches muck, 18 inches marl to sand and gravel; then 20 steps south-southwest, near center of marsh, and gravel; then twenty steps south-southwest, near center of marsh, 9 inches muck; and over 5 feet marl, without reaching bottom. Here the marl was quite white and pure: northwest of this hole a sample full of shells was taken. In general immediately beneath the muck it was full of shells, and deeper down, became a sludge. Under the microscope *Chara* material appears to be abundant.

18. (51) *Eaton County*.—On the line between Eaton and Calhoun Counties, three miles from Bellevue, there is said to be a bed of bog lime of over four hundred acres, and an average depth of 20 feet. In places it is 37 feet deep and there is but one to two feet of water above it.

There is said to be a suitable clay immediately adjacent.

Around Lacey's Lake, Kalamo township, T. 2 N., R. 6 W., is said to be a large bed of bog lime in places 20 feet thick.

19. (50) *Barry County*.—Mr. Hale has described quite fully the deposits at Cloverdale in Hope township.

Near Prairieville, the township southwest, the bog lime deposits exist, but are said not to be enough to start a cement plant upon.

To the west at Fish Lake, near Orangeville, there are extensive deposits of very good quality as shown by Prof. Fall's analyses. There are 200 acres or more of an average depth of perhaps 20 feet. There is from 0 to 2.5 feet of peat stripping on top. The deepest marl appears to be often close to the water's edge. Though a good bed it is over four miles from the railroad.

Just north in Gun Lake, between towns 2 and 3 N., R. 11 W., the relation between the thickness of the marl and the depth of water is shown by the following table of soundings.

*Chapter VI, pp. 107 to 131.

Depth of water.	Of marl.	Remarks.
4	10	
3.5	4.5	500 feet from the previous sounding.
5	27	No bottom, edge of deeper water.
3.5	....
5	20	25 feet from shore.
5	1 to 4	North end of the west lake, bottom gravel.
4	9	
3	2	
3	3	
4	2 to 4	
7	12	
8	17	
8	....	Sand at 31 feet.
7.5	22.5	
3	3	Gravel bottom.
e	r	

It is obvious that the deeper water does not always have the deeper marl.

A little farther north, Cobb Lake, Sections 5 and 8, and Barlow Lake, Sections 7 and 18 contain bog lime (said to be 93% calcium carbonate).

21. (48) *Ottawa County*.—A sample of marl from the Lake Shore west of Grand Rapids gave W. M. Courtis, M. E. the following results:

(The sample loses 6.376% of water and volatile hydrocarbon when dried at 100°.)

The dried marl contains:

Organic matter	0.790%
Combined with water less organic matter as above	0.235%
Silica (no sand)	2.528%
Tricalcic phosphate	0.150%
Chlorine as sodium chloride.....	0.119%
Alumina and a little iron.....	0.432%
Carbonate of magnesia.....	1.250%
Carbonate of lime to balance.....	94.496%
Sulphur	none
	<hr/>
	100.000%

20. (49) *Allegan County*.

22. (47) *Kent County*.—Beside a number of marl beds in the north part of the county around Cedar Springs, which have been in part described by Mr. Hale, and the insignificant deposits described in the Douglass Houghton reports, there are other large deposits. Mr. Nellist reports 13 deposits many of them first rate,

though not convenient. The largest he says is in Wabsis Lake, which is in some places over 100 feet deep (T. 9 N., R. 9 W.). An analysis by A. N. Clark gave:

Calcium as carbonate.....	90.30
Magnesia as carbonate.....	3.21
Alumina and ferric oxide.....	0.73
Insoluble in HCl, mainly sand.....	0.94
Difference, organic matter and water.....	4.82
Total	100.00

Jamberton Lake, Grass Lake, in Cannon township, and Crooked Lake all contain marl.

There is also marl in a lake on Section 21, Grattan Township, in two little lakes on Section 8, Cascade Township, and in small quantities on Sections 9 and 15, Wyoming Township.

The following is an analysis of a Kent County marl from near Cedar Springs controlled by Stewart and Barker of Grand Rapids. It will be noticed that No. 1 is an analysis of the fresh wet marl, of which we have very few, almost all the analyses being figured to dry marl, or being made on specimens already pretty well air dried.

	1	2
Insolubles (silica or sand).....	00.30	00.42
Iron and Alumina.....	.30	.42
Calcium as carbonate.....	67.66	95.04
Magnesia as carbonate	1.67	2.34
Soda and loss of dry material.....	1.27	1.78
Water and organic matter.....	28.80	
Total	100.00	100.00

The second set of figures are as bog lime analyses are often given, and show that this, except for possibly too much organic matter is a very good specimen indeed. The stripping or top layer contains much more organic matter,—up to 38%. See also Mr. Hale's descriptions in Chapter VI, § 4.

23. (46) *Ionia County*.—Jordan Lake near Lake Odessa, is surrounded by extensive beds of bog lime, which extend into Barry County. The lake lies on the line. They are convenient to the P. M. R. R.

Mud Lake just west of South Lyons also contains bog lime.

There is also said to be some near Muir.

24. (45) *Clinton County*.—In the Chandler marsh three and a half miles north of Lansing, T. 5 N., R. 2 W., there is marl, i. e., bog lime, as reported by F. R. Singlehurst.

Merle Beach, significantly named, on Muskrat Lake, T. 6 N., R. 2 W., has also deposits of bog lime over quite a large area under about a foot of peat muck.

25. (44) *Shiawassee County*.—Marl is reported right at Owosso in the Abley Addition, in the southwest corner of Owosso township. Also in the Maple River flats marl is reported in some places over 16 feet thick. Over in Gratiot County around Bannister, Mr. Davis and I did not find any marl along the Ann Arbor R. R. in the extensive marshes there.

A deposit is also reported on the farms of M. Carey, R. F. Kay and J. G. Marsh, in Woodhull township.

26. (43) *Genesee County*.—A number of deposits in this county have already been described in connection with the Detroit, Egyptian, and Twentieth Century Portland Cement plants.

Holden and Buell Lakes, Thetford township, T. 9 N., R. 7 E.

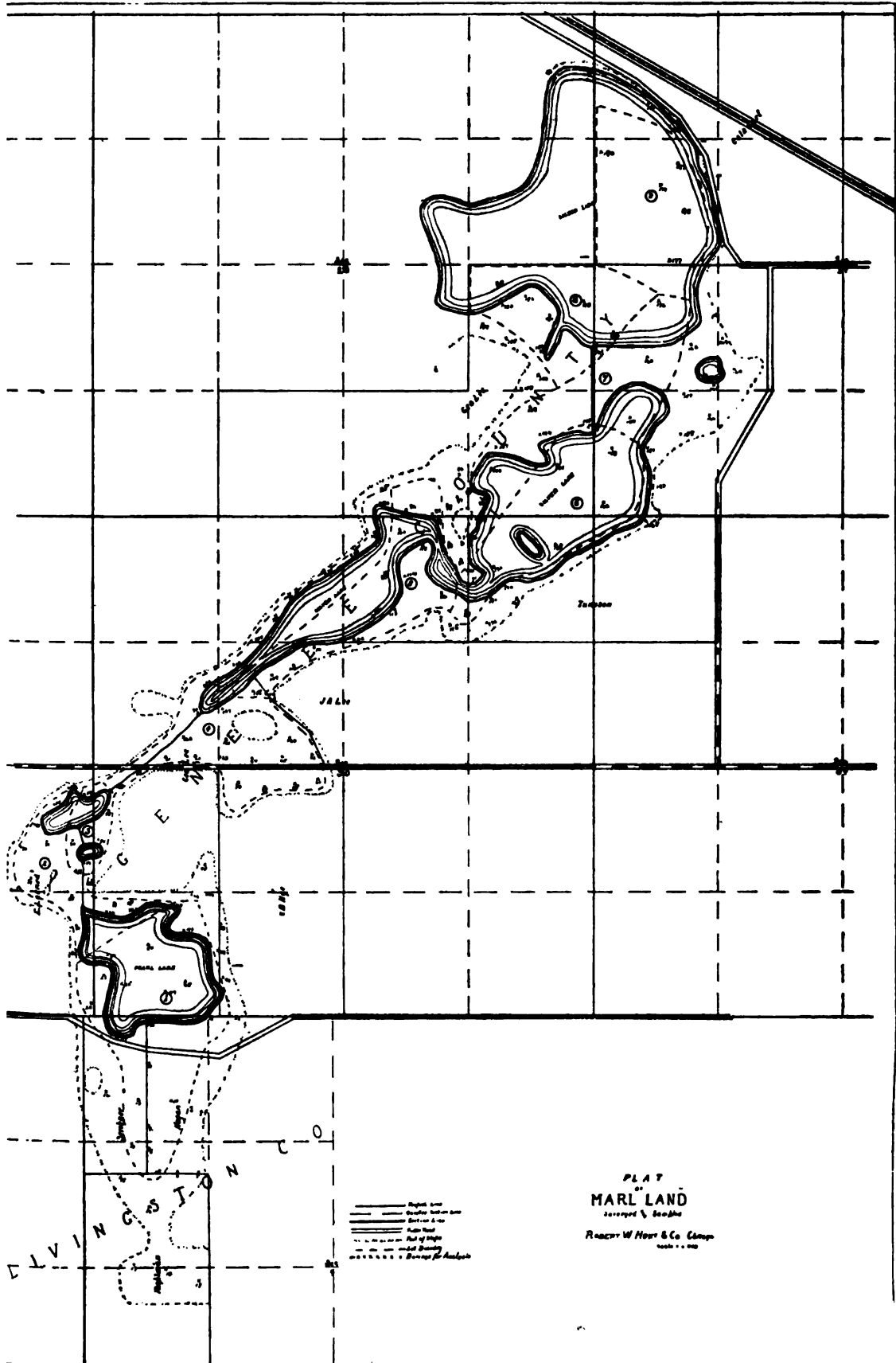
Mud Lake, Arbela township, T. 10 N., R. 7 E.

Marl properties around the above lakes were gathered together by Fred C. Zimmerman and R. Adams of Saginaw. "It appears that the depth of the deposit is anywhere from 10 to 30 feet and deeper. In Holden (Sec. 3) and Buell (Sec. 2) Lakes, where the water is shallow, it can be seen in large quantities. All these lake beds consist of extraordinarily pure marl beds of unusual depth and such consistency that it can be pumped from the bottom.

"Analysis of the material taken from these deposits made at the Ohio State University, gives the following:

Carbonate of lime.....	89.39
Carbonate of magnesia	1.95
Silica	6.29
Iron and alumina .....	.99
Organic matter	1.00
	<hr/>
	99.62"

The silica is too high if this is a fair sample of the marls, which I doubt.



SILVER LAKE MARL BEDS.

27. (42) *Lapeer County*.—In the Annual Report for 1901, Mr. F. B. Taylor says:

"There is a considerable quantity of marl in the county, and localities so far determined are shown upon the map. None of them, so far as learned, are of large enough extent to form a basis of cement works in the present stage of this industry. No beds have yet been found having an extent of over 100 acres. Because of their present unavailability mainly, the marls found have not been tested thoroughly to determine their suitability for cement. The largest swamps in the county in the eastern and northeastern parts, appear not to yield marl. Marl was formerly burned for lime in several parts of the county, most notably in southwestern Hadley, and southeastern North Branch townships. There is marl near Orion."

28. (41) *St. Clair County*.—This county may have a few small beds of bog lime in the western part but none have been reported.

29. (40) *Sanilac County*.—This county was reported in Vol. VII of our reports. Marl probably underlies a good many of the swamps, such as the "Stone wall swamp," in the western part of the county. Some beds have been tested by Cass City parties and are believed to be extensive enough to work. Their proximity to the fine shale exposures of the Lake Huron shore in Huron and Sanilac Counties might be a point in their favor.

30. (39) *Huron County*.—Deposits of marl are described in Vol. VII, and may be sought from Mud Lake northeast to Bad Axe and east to Parisville. It is not likely, however, that there are any very extensive deposits.

31. (38) *Tuscola County*.—Mud Lake in Arbela township has been mentioned in connection with the deposits in Thetford township, Genesee County, just south.

Near Cass City there are said to be big beds of marl 10 feet or more thick. Shale clays can probably also be obtained in this region, as there are exposures of the Michigan series. An analysis of the marl by Prof. Kedzie runs:

Insolubles (silica) .....	.24
Oxides of iron and alumina.....	.14
Calcium oxide (as carbonate 94.32).....	52.82
Magnesium oxide (as carbonate 2.56).....	1.25
Carbon dioxide	39.16
Difference, organic, etc., (2.72).....	6.39

Total	100.00
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The variation in the items of difference shows how much of the lime is combined as sulphate or with an organic acid.

32. (37) *Saginaw County*.—There is probably no bog lime, i. e., what the cement companies call marl, in Saginaw County, beyond possibly a few inches in swampy hollows.

What has been reported as marl, like that on the *Prairie farm*, is clay marl,—and only an ordinary surface clay free from grit. For instance, E. Wetzel opened a bed of clay at *Zilwaukee*, eight feet down and about twelve feet thick, which gave H. & W. Heim on analysis:

	Top.	Bottom.
Silica and alumina.....	65.1	63.75
Calcium carbonate.....	20.4	20.9
Difference	14.5	15.35
Total	100.00	100.00

33. (36) *Gratiot County*.—Five miles west of Alma is a small bed of 30 acres from 4 to 16 feet deep.

Cedar Lake District.

34. (35) *Montcalm County*.—Montcalm County is full of lakes, many of them containing more or less marl. The neighborhood of Cedar Lake, a few miles east of Alma, shows an interesting variety of occurrence of marl and has been somewhat investigated, as shown by Fig. 31 and the following description:

Bass Lake occupies a hollow in the sands. The shore is sandy and there is no outlet. Rock Lake is similar but the surroundings are somewhat more gravelly. Marl Lake has already been referred to by Mr. Davis.* The water is pure, milky white, and this he attributed to the fact that there is a bench about 100 yards wide of pure marl around the lake over which the water is shallow, from two feet down. There is no peat covering over this bed. This we notice in the diagram of soundings (Fig. 31), and we notice too that soundings 5, 9 and 13 outside the shore of the lake show no marl.

Mr. Jno. Webster's estimate of marl on this lake is of marl 12 feet thick, 100 yards wide, over a circumference of 5,186 feet, i. e., 6,220,800 cubic feet. It is quite likely that there is two or three times as much as this.

On the other hand, about Cedar Lake, which is slightly higher, the conditions are entirely different. The marl is covered with peat

*Page 83.

and at the edge, which is the margin of the lake, drops off to 30 feet depth very rapidly. The peat varies, as we see in the diagram of soundings, from one to five feet thick, being generally about three feet thick.

The land south of the railroad rises rapidly 175 feet or more, and the lake lies in a valley in the till. As bearing on the origin of the marl, it is worth noting that an upward pressure of the ground water is shown by three flowing wells on the road from the station to the lake, which penetrate the drift to a depth of 48 feet. The

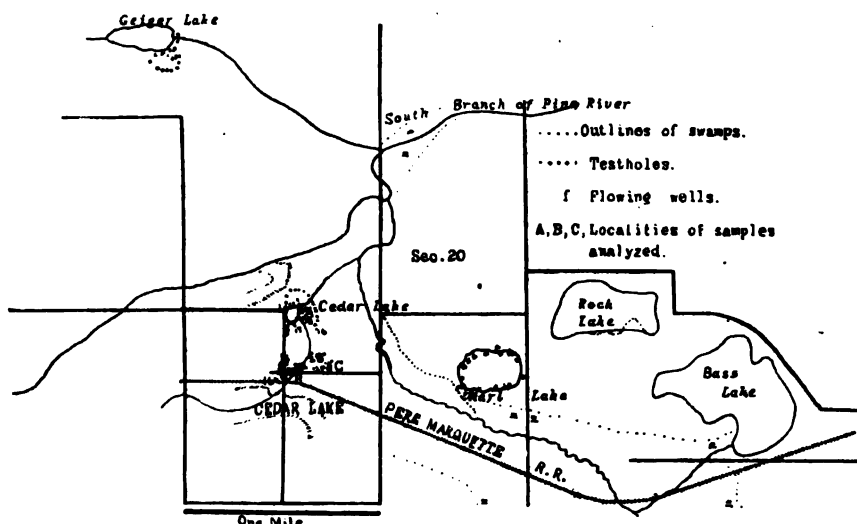


Fig. 31. Sketch map of the lakes near Cedar Lake Station of the Pere Marquette R. R., T. 10 N., R. 5 and 6 W.

temperature of these wells is for the first one 49° F., and for the one nearest the lake 48.3° F. It is quite likely that Cedar Lake is deep enough to come pretty near to the artesian stratum and allow considerable upward seepage. This is of interest in considering the origin of the marl. An analysis by R. C. Kedzie of clay brought to the surface by one of these wells, is as follows:

Silica, soluble	60.00
Sand	3.00
Calcium as carbonate* (CaCO ₃)	18.31
Magnesium as carbonate (MgCO ₃)	3.00
Alumina and oxide of iron	14.80
Difference (water or losses) .....	.89
	<hr/>
	100.00%

*It is probable that the lime and magnesia are not all carbonate, hence the difference is too small.

This would not be a bad Portland cement clay so far as the analysis goes, but it is one of the common surface calcareous clays and it is not likely that the lime would come twice alike.

Cedar Lake is quite a little lower than the railroad station and the water level seems to have been falling. This may have helped the peat to spread more rapidly over the marl, and helps to account for the marl extending considerably above the present level of the lake, a meadow north of the station showing a considerable thickness of marl, analyses B and C. In this latter place it is cut into by the stream. When the material for analyses A and B was taken the marl was 22 feet thick with about one-half foot of muck on top.

Of B, which is near the railroad, a sample barrel was shipped to the H. S. Mould Co., for briquetting, and they report that it can be successfully handled at a cost not to exceed 50c a ton.

ANALYSES.

Analyst.	F. S. Kedzie.		F. S. Kedzie.		R. C. Kedzie.	
	No. A.		No. B.		No. C.	
	Wet.	Dry.	Wet.	Dry.	Clay.	
Insoluble matter.....		73		1.58		
Alumina.....		26		.10	.30	
Iron oxide.....		52.54		52.36		
CaO as carbonate.....		1.24		.97	60.00	
MgO as carbonate.....					3.00	
CO ₂		42.00		41.12		
Organic matter.....		3.23		3.86	1.50	
Water.....	29.95		34.81		34.60	
Difference.....	70.05		65.19			
	100.00		100.00		100.00	

Around Cedar Lake, Mr. Webster estimates, see Fig. 31, 13 feet of marl on 20 acres, i. e., 11,325,600 cubic feet, and tributary two acres 11,174,400 cubic feet beside.

Around Geiger Lake (Fig. 31), he finds six and one-half acres 12 feet thick, or 3,136,320 acres. These estimates are certainly very conservative, and as Mr. Webster himself says, a larger amount of time in testing would have materially increased the amount upon which he could surely estimate. Altogether in the region there is said to be some 700 acres of marl lands, options upon which were held by W. S. Nelson and George Reed. Cedar Lake has furnished some of the material for microscopic tests, and for Prof. Davis's experiments.

The Cedar Lake marl is very pure Chara lime, and there is just a small residue, in which angular quartz grains, rarely as large as 0.07 mm occur. There is one well terminated crystal of tourmaline, prismatic with blunt rhombohedral terminations, the two ends slightly different in tint, with appropriate refraction, bi-refraction, and pleochroism.

Riverdale.

Just east of the Cedar Lake district in Gratiot County is Riverdale,—where the Pere Marquette crosses the Pine River. The valley here is much too large for the Pine, being an old gravel filled drainage channel of the ice. Southwest of the village, toward a small pond known as Mud Lake, is a swamp covered with peat, underlain with marl toward the center. The peat cover is thicker toward the margin of the swamp.

This also is in a region where flowing wells occur at a shallow depth (38 feet).

In Mud Lake marl, from near Riverdale, the cell walls appear as dark lines, with more coarsely polarizing matter between as the calcite radiates from them. There are also bodies, fruit or spores (?) with a little greater index than balsam, spheroidal in shape, with yellow polarization colors and a distorted black cross of + character, and a diameter of about 0.04 mm.

Olson Lake and a number of other lakes near Howard City contain bog lime, and some of them have been already described by Mr. Hale.

35. (34) *Muskegon County*.—A sample of marl has been sent by Mr. Keating of the Muskegon Board of Trade, but no extensive deposits have been made public. Mr. Hale found nothing pure.

36. (33) *Oceana County*.—H. Kennedy is said to have on his farm in Rothbury, a lake whose bottom is rich in fertilizer (?) of a marly nature.

Marl is also said to have been found near Pentwater.

37. (32) *Newaygo County*.—Some of the deposits of Newaygo County have been quite fully described in connection with the Newaygo plant and by Mr. Hale.

A sample of marl from Fremont Lake gave:

	Prof. Fall.	Prof. F. S. Kedzie.	
Silica.....	2.28	.....	3.98
Iron and alumina.....	1.60	.....	.30
Calcium as carbonate.....	88.25	(44.48CaO)	79.44
Magnesia as carbonate.....	1.40	(1.59MgO)	2.91
Difference, organic and loss.....	6.47	.....	18.33
	100.00		100.00

Direct estimate gave Prof. Kedzie 34.54 CO₂ and 15.36 organic matter and loss. Thus the indications are that in this marl the CaO is combined in part with an organic acid.

An adjacent surface clay gave Prof. Kedzie:

Silica	38.36	
Alumina (and ferric oxide)	22.18	
Calcium oxide	13.96	
as carbonate		24.96
Magnesium oxide	8.19	
as carbonate		17.12
Carbonic oxide	16.45	
Difference, organic matter, alkalies and loss .....	.86	
	100.00	102.62

38. (31) *Mecosta County*.—In the neighborhood of Barryton are said to be marl beds from 20 to 300 acres in extent (T. 16 N., R. 7 W.).

The beds around Pierson are described in Sec. 3 of Chapter VII.

39. (30) *Isabella County*.—The Littlefield Lake deposit has already been described by Mr. Davis, and in connection with the Farwell P. C. Co. It is probably the best in the county.

40. (29) *Midland County*.—This county probably contains no large deposits of bog lime.

41. (28) *Bay County*.—The shale clays of this county, developed by the coal mines, have been mentioned in connection with the Hecla P. C. and C. Co. There are probably no large deposits of bog lime, unless possibly in the extreme north.

42. (27) *Arenac County*.—There is not much bog lime in this county, though there is some valuable limestone. There may be a little under the marshes of the west end.

43. (26) *Gladwin County*.—Extensive beds are reported within a mile of the county seat, and there may be others northwest.

44. (25) *Clare County*.—See description of the beds of the Clare Portland Cement Co.

45. (24) *Osceola County*.

46. (23) *Lake County*.—The principal beds here are probably in the possession of the Great Northern P. C. Co., and have been previously described.

A bed is reported on Section 3, T. 20 N., R. 14 W.

47. (22) *Mason County*.—Large beds are reported near Millerton on the line of the Manistee and Grand Rapids R. R., near the west line of Lake County.

48. (21) *Manistee County, and region of the Manistee and Northeastern R. R.*

Through the courtesy of J. J. Hubbell, chief engineer of the Manistee and Northeastern R. R. we have the result of their work of investigation which he has superintended, to add to the notes of Mr. Hale on his trip. This region includes:

49. (20) *Wexford, and also Benzie, Grand Traverse and Leelanau Counties*.

The collection embraces some 52 clays and marls of which samples were taken, and turned over to us in their case.

Many of the surface clays, though calcareous as usual, run lower in carbonates than those from other parts of the State as the following group of analyses shows, in which, however, the magnesia is so high relative to the lime as to show that the material is dolomitic. Such clays will hardly effervesce with cold acid, and may thus pass for better cement clays than they really are.

Lab. No.....	592	593	594	595
Mark	65	66	67	68
Silica	61.94	56.64	61.10	59.36
Alumina	11.58	12.18	13.91	12.38
Iron (ferric) oxide....	3.49	8.59	3.62	3.62
Calcium oxide	5.92	8.17	6.32	5.63
Magnesium oxide	4.85	4.29	3.91	4.62
Sulphuric anhydride..	.18	.31	.31	.30
Difference, CO ₂ , organic, alkalies, etc.....	12.04	14.82	10.83	14.09
Total	100.00	100.00	100.00	100.00
Calcium as carbonate*.	10.6	14.6	11.3	10.1
Magnesium as carbonate	10.1	9.0	8.2	9.7
Total dolomitic matter	20.7	23.6	19.5	20.2
Difference to balance, organic, alkalies, etc	2.11	3.48	1.56	4.14

*Calculations below totals are by A. C. Lane and not by analyst.

W. H. Simmons of Bronson, Chemist, Dec. 17, 1900.

The following are some of the clays:

No. 1A. East Lake, Sec. 4, 5, T. 21 N., R. 17 W., 4 feet thick; 1 to 2 feet of sand stripping, a smooth, pink brick clay, surface, high in lime with a trace of sand.

No. 1B. Same location, 5 to 10 acres of it, 2 feet thick; 2 feet muck stripping, with no sand and but a trace of lime. A smooth blue clay.

No. 2. Arendale Hill, Sec. 15, T. 22 N., R. 16 W.; extensive quantity, with 2 to 4 feet stripping; very high in sand and high in lime. A pink brick clay, but probably with some small pebbles.

No. 4. Onekama, Sec. 25, T. 23 N., R. 16 W.; extensive quantity, with light stripping, no sand, but a moderate amount of lime; in appearance like 1A.

No. 5. Manistee, Sec. 31, T. 22 N., R. 16 W.; moderate quantity, with 3 feet stripping, a trace of sand and high in lime; a laminated, pinkish, fine grained clay.

No. 6. Copemish, Sec. 7, T. 24 N., R. 13 W.; small quantity, with 2 to 4 feet stripping; no sand, and a moderate amount of lime; a smooth, pink plastic clay.

No. 7. Betsey River ("Aux Becs Scies"), Sec. 10, T. 24 N., R. 14 W.; quantity large and stripping light; sand high, and moderate amount of lime; a massive, pink clay.

No. 8. Horicon, Sec. 9, T. 25 N., R. 12 W.; a limited quantity of clay with heavy stripping; with no sand, but much lime; a blue clay, till clay, with small limestone fragments.

No. 9. Carp Lake, Sec. 1, T. 28 N., R. 12 W.; large quantity with light stripping; only a trace of sand, and a moderate amount of lime; a tough, plastic, pinkish clay.

No. 10. Duck Lake, Sec. 26, T. 26 N., R. 12 W.; limited amount with heavy stripping; no sand but high in lime; a pink clay.

No. 11. Cedar Run, Sec. 6, T. 27 N., R. 12 W.; moderate amount with 4 to 6 feet of stripping; no sand, and a moderate amount of lime; looks much like 1A; a smooth, pink clay.

No. 12. Carp Lake, Sec. 15, T. 28 N., R. 12 W.; quantity limited and stripping 5 to 19 feet; with no sand but high in lime; compared with No. 9 it appears smoother and more uniform.



GENERAL VIEW NEWAYGO PORTLAND CEMENT CO'S PLANT.



METHOD OF EXCAVATING MARL.

No. 13. Traverse City, Sec. 28, T. 28 N., R. 11 W.; large amount, with no stripping; a smooth, pink clay. Analysis:

Sand	00.00
Silica	29.06
Magnesia	2.07
Lime (carbonate?)	50.02
Alumina	12.03
Iron (oxide?)	5.02
Difference	1.80
	<hr/>
	100.00

No. 14. Sherman, Sec. 31, T. 24 N., R. 11 W.; limited amount; too much stripping; sand but a trace, but lime heavy; a cream-colored clay.

No. 16. Platte River, Sec. 14, T. 27 N., R. 14 W.; amount limited, and too much stripping; with no sand, but a trace of lime; a deep red, plastic clay; would be a valuable clay if favorably located.

No. 17. Platte River, Sec. 29, T. 27 N., R. 14 W.; amount limited, but stripping light; only a trace of sand and lime; a red clay, similar to No. 16; a valuable clay, but I suspect that the lack of lime is due to leaching, and would not be found persistent.

No. 20. North and east of Wexford, Sec. 23, T. 25 N., R. 11 W.; amount small, and amount of stripping unknown; high in sand and lime; a buff, brick clay.

No. 22A. Dean's Mill, Sec. 30, T. 24 N., R. 11 W.; one hundred acres of it, with 1 foot of stripping; no sand and only a trace of lime; a buff clay with roots in it; valuable if not merely a superficial layer.

No. 22B. Dean's, Sherman, same section; a large amount directly under 22A; analysis as follows:

Sand	trace
Silica	41.76
Alumina and iron oxides.....	17.16
Lime (oxide?).....	16.00
Magnesia	5.62
Loss (on ignition?).....	19.02
Difference	0.44
	<hr/>

Total 100.00

This analysis shows that the clay 22A is probably due merely to superficial leaching, and will be irregular in thickness. No. 22B is a smooth, pink clay with a resemblance to No. 1A, etc.

No. 22C. Dean's, Sherman, same locality and directly under 22B; large amount; analysis as follows:

Sand	trace
Silica	47.68
Aluminum and iron oxides	17.70
Lime (oxide?)	12.50
Magnesia	5.38
Loss	16.42
Difference	0.32
Total	100.00

A drab, plastic clay, a shade bluer than 22B.

No. 22D. Dean's Mill, same section; stripping of 22C; amount extensive; with no sand, and only a trace of lime, according to report, but the sample with the survey effervesces freely; apparently the same as 22C.

No. 23. Northport, Leelanau County, Sec. 10, T. 31 N., R. 11 W.; large amount, but 3 feet of stripping; no sand and a moderate amount of lime; a good deal like the clay at Manistee, No. 5.

No. 24. Meesick, Sec. 11, T. 23 N., R. 12 W.; large quantity with light stripping; no sand, and a moderate amount of lime, much like No. 23.

No. 25. Eddington farm, Sec. 25, T. 27 N., R. 13 W.; extensive quantity with light stripping; high in sand, and moderate in lime; a dark red clay, with some small pebbles. Apparently a till clay of little value.

No. 26A. Stanley's clay, Harrietta, Part I, p. 3, this report, probably, large amount with 2 or 3 feet of stripping; analysis (compare analysis 24 of Part I):

Sand	0.00
Silica	55.60
Magnesia	12.00
Loss on ignition (?).....	15.60
Difference (calcium oxide?).....	16.80

No. 27. Carp Lake, Sec. 12, T. 28 N., R. 12 W.; amount limited and stripping heavy; no sand but much lime; much like 26A.

No. 28. Carp Lake, same section as No. 27; large amount and no stripping; no sand and moderate amount of lime; one of the common, smooth red clays.

No. 29. Manistee, Sec. 30, T. 22 N., R. 18 W.; large amount and no stripping; much sand and a moderate amount of lime; contains some small pebbles,—a till clay.

No. 30. Monroe Center, Sec. 6, T. 25 N., R. 11 W.; large amount, with 1 to 3 feet of stripping; no sand and no lime; a greenish, somewhat vari-colored clay, and if the sample is a fair one, it ought to be a very valuable clay.

No. 31A. Russell's farm, Sec. 22, T. 21 N., R. 18 W.; a very large amount with no stripping; only a trace of sand and a moderate amount of lime; one of the common type of smooth, pink plastic clay.

No. 31B. Russell's farm, same location; 2 to 3 feet thick with No. 31A as a stripping; with much sand and a moderate amount of lime; these two clays together could be nicely combined in making brick.

No. 32. Sherman, Sec. 31, T. 24 N., R. 11 W.; large amount with light stripping; no sand and no lime; smooth, with a greenish tinge; apparently a valuable clay for cement or other purposes.

No. 33. Near Sherman, Sec. 25, T. 24 N., R. 12 W.; large amount with light stripping; no sand and a moderate amount of lime; a smooth, pink plastic clay.

No. 34. On Manistee River, Sec. 10, T. 23 N., R. 12 W.; amount unknown, but no stripping; no sand and a moderate amount of lime; a smooth, red clay.

No. 35. Bear Creek, Sec. 6, T. 22 N., R. 14 W.; very large amount with very light stripping; no sand and a moderate amount of lime; a very smooth clay, in color between blue and purplish drab.

No. 36. Platte township, Sec. 29, T. 27 N., R. 14 W.; limited amount with light stripping; only a trace of sand or lime; the sample, however, is a common pink clay, probably a till clay, with small pebbles, and free effervescence in acids.

No. 37. State Lumber Co., S. W. quarter of N. E. quarter, Sec. 22, T. 26 N., R. 14 W.; high in sand with a trace of lime; a pink clay.

No. 38. Jas. Case, Homestead P. O.; southwest quarter of north-west quarter, Sec. 22, T. 26 N., R. 14 W.; no sand and moderate in lime.

No. 39. Carp Lake, Sec. 12, T. 28 N., R. 12 W.; see No. 9; large amount, with moderate amount of stripping; a trace of sand and moderate amount of lime; a reddish clay.

No. 40. Carp Lake, same location as No. 39; a large amount with moderate stripping; similar in sand, lime and appearance.

No. 42A. Brosch Estate, Traverse City, Sec. 1, T. 27 N., R. 11 W.; 80 acres of it, 2 feet thick; stripping light; analysis:

Sand	00.00
Calcium oxide.....	3.15
Magnesium oxide.....	0.31
Aluminum and iron oxides.....	32.79
Silica	60.62
Difference	3.13
Total	100.00

No. 42B. Same location as 42A; 80 acres of unknown depth, with 2 feet of stripping; no sand and a moderate amount of lime. This appears to be the main bed of reddish clay, of which A is a superficial layer, produced by leaching. They are very similar in looks.

No. 43. B. Hoke, Sherman, southwest quarter of the southwest quarter, of Sec. 29, T. 24 N., R. 11 W.; moderate amount with light stripping; high in sand, and moderate in lime; a blue clay.

No. 44. Southeast quarter of the southeast quarter, of Sec. 18, T. 24 N., R. 12 W.; with a trace of sand and moderate in lime; a pink clay.

No. 45. Corey, Wexford Corners, northeast quarter of the northwest quarter, Sec. 18, T. 24 N., R. 11 W.; with a trace of sand, and moderate in lime; a pink clay.

No. 47A. Lake Bluff, north of Leland, Sec. 4, T. 30 N., R. 12 W.; bluff 200 feet high, with no stripping; free from sand with a moderate amount of lime; a typical pink till clay; the sample is not free from pebbles and sand, though they are not abundant.

No. 48A. Lake Leelanau, Sec. 11, T. 30 N., R. 12 W.; large amount with light stripping; no sand but high in lime; a smooth, pink clay.

No. 48B. Lake Leelanau, layer below 48A; similar in character; very smooth.

No. 48C. Lake Leelanau, layer below 48A; similar in character.

No. 52. Sec. 19, T. 24 N., R. 11 W.; small amount with heavy stripping; a large amount of sand, but low in lime.

No. 53. Clay to be used at Baldwin; a smooth, pink clay, freely effervescing; one of the common surface clays. No. 60 is a calcareous shale from the bay shore near Petoskey. No. 15 was a clay from the foundation of the new pumping station at Detroit, of the water-works; a green sand clay, freely effervescing. The remaining numbers are of marls, many of them not along the line of the road.

No. 54 was a very fine specimen of almost pure calcium carbonate, bog lime, or marl, from Baldwin.

No. 55 was supposed to be an average sample, perhaps not quite so fine, showing some root marks and some shells.

No. 56. Bronson Lake, Sec. 4, T. 26 N., R. 13 W.; a widening of the Platte River; dark blue with quite a number of shells.

No. 57 is from Newaygo.

No. 58. This is from the "Bigmarsh," a filled lake connected with the Betsey ("Aux Becs Scies") River, Sections 1 and 2, T. 25 N., R. 13 W.; said to cover 988 acres, varying from 6 to 35 feet in depth, and (as a result of 600 soundings) to contain about 23,000,000 cubic yards. The sample has a slight bluish tinge, and a good many shells, and appears quite as good as most commercial marls, that of the Peninsular plant, for instance.

No. 59. From Carp Lake, Sec. 24, T. 30 N., R. 12 W.; at the narrows; a good-looking, bluish marl.

Besides these deposits of bog lime, there are in this district:

Mr. Farr's deposit at Portage Lake, Onkama, already described by Mr. Hale.

A deposit in the south end of the lake at Arcadia.

A deposit in Little Platte Lake, Sec. 36, T. 26 N., R. 15 W.

The deposits in Upper Herring Lake, controlled by the Water-vale P. C. Co., already described.

A deposit at the head of Carp Lake, Sec. 10, T. 28 N., R. 12 W., as well as that at the narrows, already mentioned.

On the north side of Glen Lake, Sec. 26, T. 29 N., R. 14 W.

In Traverse Lake and perhaps Lime Lake, T. 29 N., R. 13 W.

50. (19) *Missaukee County.*

51. (18) *Roscommon County.*

52. (17) *Ogemaw County*.—Beside the extensive deposits of bog lime described in connection with the Hecla cement plant, and the projected plant at Lupton, the same is reported from:

Gamble Lake, Sec. 11, T. 23 N., R. 3 E.

Devore Lake, Sec. 11; same township.

Sage Lake, a large lake in the south central part of T. 23 N., R. 4 E.

As there are probably outcrops on the Rife River of the Michigan and coal series, it is likely that good shale clays may be found in the county, although as already remarked, the Hecla plant plans to go to the coal measure shales of Bay County for theirs.

53. (16) *Iosco County*.—Valuable marl beds are said to have been found near East Tawas by H. C. Bristol.

The Michigan series of outcrops in this county at Alabaster, and up the Au Gres River, and exposures of argillaceous limestone, suitable for rock cement and probably of shale clays for mixing in Portland cement occur.

The following analysis, is I think, from one of these clays, taken from near Alabaster and Sherman, and analyzed for R. A. McKay of Bay City by F. S. Kedzie:

Silica	58.95
Aluminum oxide	14.45
Iron oxide.....	7.60
Calcium oxide.....	2.94
Magnesium oxide.....	.86
Sulphuric anhydride (SO ₃).....	1.73
Alkalies as K ₂ O.....	2.54
Water of combination.....	7.50
Difference, organic matter and loss.....	3.43
Total	100.00

Its freedom from lime or grit, and high per cent of silica are valuable qualities.

54. (15) *Alcona County*.—In the annual report for 1901 some details are given regarding the bog lime deposits of this county (pp. 60 to 65) as follows. The deposit north of Harrisville about three miles, near what is known as Ludington's Spring, received some attention in the summer of 1899.

"Marl deposits in Alcona County, so far as examined, were found to be too thin to be utilized in the cement industry. There is from 6 to 10 feet of rather impure marl in the lake on the township line a mile west of Lincoln. About 6 feet of marl, apparently of good

quality, was found on the border of Tubb's Lake in Sec. 31, T. 26 N., R. 7 E., forming a platform 10 or 12 rods wide. Marl deposits 1.5 to 2 feet thick are exposed in a railway ditch in a swamp one-half mile north of Harrisville station, and a similar depth in railroad ditches south of Greenbush on the west side of Cedar Lake.

"Deposits of what is popularly known in Michigan as marl, but is nearly a pure calcium carbonate, occur at a number of points, at Springport (South Harrisville), Kirk Ludington's, Shabno's, four miles south of the Presbyterian church in T. 27 N., R. 9 E., etc.

"A very interesting deposit in some ways is one that is crossing the lake road about three miles and a half north of Harrisville.

"It covers probably not less than 20 acres. I do not know how deep it is, though it has been tested.

"The interesting thing, however, is its mode of occurrence, which is directly in front of the bluffs worn by the lake at a higher level, with no ridge or barrier between it and the present lake. It is wasting away, but the upper part is redissolved and precipitated and passes into a firm and hard calcareous tufa, while as one goes down, it becomes granular and then soft. It appears to be a genuine Chara lime formed by the precipitation of lime by the lake weed known as Chara, but it can hardly be supposed to have been found in such purity directly on the beach of a great lake, and we are forced to assume that it is the relic of a small lake, the rest of which has been eroded away.

"There is enough, perhaps, for lime kilns, but hardly, I think, for a cement plant; and, beside, it is so hard and granular on top that the advantage of marl, its fine sludgy character suitable for mixing, would be lost.

"In general, clay deposits of fine and uniform texture are rather rare in Alcona County, but in the southeast part there is considerable clay that carries but few pebbles, an area of several square miles being found around Mikado and northward from there between Gustin and Killmaster. Although an unsuccessful attempt has been made to burn a kiln of brick at Mikado, it seems probable that the surface clay will in many cases prove suitable for brick or tile. It will at least be worth while to experiment further with the clay, for that part of the county would be greatly improved by underdraining with tile, and it will be an advantage to manufacture the tile where it is to be used.

"At South Harrisville, Sec. 32, T. 26 N., R. 9 E., some brick has been made of glacial clay. It is not entirely free from pebbles, effervesces somewhat and makes cream-colored brick. Some brick has been made also at Mikado (West Greenbush) of a similar quality. All the clays of the county are Pleistocene or surface clays, and it is the almost universal rule that such clays have more or less calcium and magnesium carbonate. Generally the top of the bed is free from carbonates, which have been leached out.

"Just at Harrisville the stream falls over a smooth, well-bedded clay, apparently an old lake clay free from pebbles. If not, it could easily be washed free by the stream.* Back of Sturgeon

*As at Sebewaing, see Vol. VIII, Part I.

Point, on Sec. 25, T. 27 N., R. 9 E., are fields where a similar clay appears to be present, but it is particularly well exposed where the Black River opens out from the hilly moraine country to the swampy land of the old lake bottom on Sec. 3 of the same township and Sec. 34, just north. Here a calcareous clay is extremely well exposed in the bed of the stream, appearing almost as though it were bed rock. But probably the same bed of clay also appears in the bluffs of the outer valley above the flood plain and at least 10 feet above the river. Here it is light reddish in color, does not effervesce with acid, lies close to the abandoned track of an old logging railroad, and could be readily worked. I should think it would make unusually good brick and tile (see analysis below), though it is quite possible that farther working and testing with auger would show that in going deeper more lime was encountered. Still it is quite likely that an important top layer may have been leached free.

"There are indications that similar clays occur all the way along, but somewhat below and nearer the shore, the highest former shore line of Lake Huron (645 to 655 A. T.).

"The Au Sable River also flows at several points over firm, well-bedded pink clays, apparently free from pebbles but full of lime. A good place to observe them, however, is in a little side stream at Bamfields, Sec. 11, T. 25 N., R. 5 E., where they are well exposed.

"Three typical samples of the clays were sent to the McMillan Chemical Laboratory, Albion, for analysis, and the following reports were received from Prof. Delos Fall:

	910.	911.	912.	Millbury.
Free sand.....	13.98	11.53	38.55	
Combined silica.....	27.60	25.71	22.73	
	41.58	37.24	61.28	61.08
Alumina.....	12.58	7.08	16.37	18.10
Oxide of iron.....	3.59	3.69	5.59	6.66
Calcium oxide.....	13.04	17.70	2.33	1.29
Carbonic oxide.....	17.26	21.00		
Calcium carbonate.....	23.28	31.60		
Sulphur anhydride.....	0.41	0.41	0.67	1.55
Magnesia*.....	6.44	6.52	1.21	.53
Org. Matter.....	3.72	3.46	9.14	9.20
Difference, principally alkalis.....	98.62 1.38	97.40 2.60	96.59 3.41	
	100.00	100.00	100.00	

"No. 910 is the ordinary calcareous clay or marl of the district from Black River near the water level, and is free from pebbles or grit. It will be seen that it is composed of about one-third very fine sand or rock flour, one-third clay proper, and one-third dolomite. It may be used for making brick, but will yield a light brick that will not stand hard burning.

*There is not enough CO₂ to combine with all the lime and magnesia, hence there is probably some hydrous magnesian silicate present. L.

"Samples of clay from the Au Sable valley appear to have similar composition.

"No. 911, from the old brickyard southeast of Harrisville, is a typical tile clay and contained some small limestone pebbles. It will be seen that it contains even more lime, nearly half. Neither of the clays appear to be suited to the higher uses for clay.

"No. 912, the third clay, which lies over No. 910 and may be derived from it by solution of the calcareous material, is of an entirely different character. If the silica is finely divided enough, and I think it is, it would make an excellent clay to mix with Portland cement for the manufacture of marl. I have given an analysis of the Millbury, Ohio clay, which is largely used in the State for cement manufacture, for comparison.

"It would also make an excellent grade of red brick, and very probably also paving brick. It remains to be seen by a series of borings how much of this clay there is, but in all probability field tests showing whether it effervesces with muriatic acid will be sufficient to show this."

55. (14) *Oscoda County*.—There are probably considerable beds of bog lime, but little is as yet known of them. Some is reported about 5 miles west of Luzerne, near Tyrrell, T. 26 N., R 1 E.

56. (13) *Crawford*.—There is a deposit of bog lime close to Grayling. The analysis given in the Agricultural Bulletin, No. 99, is in error.

An analysis of the Grayling marl by W. M. Courtis, M. E., is as follows:

Water lost at 100°C	61.
Dried marl	49.
Moisture	0.60
Organic matter.....	9.80
Insoluble silica	0.78
Soluble silica	0.13
Ferric oxide.....	1.13
Alumina	0.07
Calcium carbonate.....	87.00
Magnesium	0.91
Sulphuric acid.....	0.27
	<hr/>
	100.69

Same sample figured without the organic matter is:

Calcium carbonate.....	97.00
Silica	1.01
Ferric oxide.....	1.26
Alumina	0.08
Magnesium carbonate.....	1.01
Sulphuric acid.,.....	0.30
	<hr/>
	100.66

57. (12) *Kalkaska County*.

58. (11) *Grand Traverse County*.—Some of the beds of this county have been described in connection with the Elk Rapids Portland Cement Co., and the work of Mr. Hubbell for the Manistee and Northeastern R. R.

59. (10) *Benzie County*.—The beds of this county have been largely described in connection with the Watervale plant, by Mr. Hale, and in connection with the Manistee and Northeastern R. R. A bed of 100 acres is reported near Aral.

60. (9) *Leelanau County*.—Some beds of this county have been referred to in connection with the explorations of the Manistee and Northeastern R. R.

61. (8) *Antrim County*.—The Elk Rapids factory is located in this county. Beside this company the "Lake Shore Cement Company" (G. W. Davis of Mt. Pleasant, S. B. Daboll of St. Johns, and others), have obtained options on the lime deposits of Intermediate (which Mr. Hale has described, p. 142, as Central Lake), Grass and Clam Lakes, some 600 acres in all it is said. The shores of this county contain, as I believe, valuable exposures of shale clay.

63. (6) *Otsego County*.

64. (5) *Montmorency County*.

65. (4) *Alpena County*.—There is marl, limestone and clay, abundant in this county. See the description of the Alpena Portland Cement Co. and the Annual Report for 1901. The limestones I believe to be especially valuable.

We have also an analysis of an Alpena County marl, by W. M. Courtis:

Carbonate of lime.....	74.48
Carbonate of magnesia.....	0.50
Silica	7.20
Alumina	0.54
Ferric oxide.....	2.36
Sulphuric acid.....	0.89
Organic matter.....	12.88
Water	1.25
	<hr/>
	100.10

66. (3) *Presque Isle County*.—The conditions of Alpena County are repeated here.

The following are analyses of a limestone and yellow clay shale south of Rogers City, which I owe to Mr. J. G. Dean of Hassan, Tagge, and Dean of Detroit:

Limestone.

Silica	0.62
Alumina and ferric oxide.....	0.20
Calcium carbonate.....	98.34
Magnesium carbonate.....	0.45
Sulphur anhydride.....	tr.
Organic	0.09
	<hr/>
	99.70

Shale Clay, Yellow.

Silica	66.39
Alumina	13.60
Ferric oxide	5.87
Calcium oxide .....	.99
Magnesium oxide .....	.50
Sulphur anhydride	1.00
Organic, etc.....	10.32
	<hr/>
	98.67

There are said to be marl beds half a mile from the court house. Only about two feet of stripping are said to be needed.

67. (2) *Cheboygan County*.—Very extensive deposits of marl are reported on Black (otherwise called Cheboygan) lake. The little steamer *Eva* of the Onaway-Cheboygan mail line is said to plough through acres of it in the bed of Lower Black River, between Stony Point and Taylor's Landing. Limestone also occurs frequently.

Beds are reported 5 miles from Mullett Lake, and at other places. A sample has been sent me, said to come 7 miles from Wolverine, close to the county line, west and a little south, T. 33 N., R. 3 E., probably near the Cobb and Mitchell lumber R. R., extending over 160 acres, and said to be enough to make 16,000 barrels of cement.

This deposit or another near by has been described as occurring in a dried up lake which has a trout stream flowing from it, but no distinct inlet in an area perhaps 40 rods by 160 rods, and in thickness 7 feet or so. It is bluish, effervesces freely, but not as rapidly as many marls, and appears to be clayey or magnesian. Turns the acid somewhat amber, mainly from a little organic matter.

68. *Emmet County*.

69. *Upper Peninsula*.—The marls of the Upper Peninsula have been relatively little investigated. Beside the account given by Mr. Hale of beds near Munising, Wetmore, Manistique, Corrine, we have the following notes:

At the World's Fair in Chicago Dr. W. H. Tucker made an exhibit of the marls from Naubinway, Mackinac County. He reports them to exist in large quantities, lying in a bed some 10 feet in thickness, which is overlain by but 6 inches of a mixture of marl and vegetable mould. The analysis is reported by him to be as follows:

Insoluble matter	3.25
Alumina and iron.....	0.52
Carbonate of lime.....	92.79
Carbonate of magnesia	2.27
Organic matter by difference.....	1.17
	<hr/>
	100.00*

Compare the deposit at Corinne near by described by Hale, p. 140.

A large deposit of marl is said to exist close to St. Ignace, discovered by John Prophet.

*Report of the Board of World's Fair Managers.

Near Manistique large deposits of marl are said to be controlled by the White Marble Lime Co.

North of Menominee, T. 34 N., R. 26 E., there are said to be lakes with marl, and near Stephenson.

A very good sample has been sent in by W. B. Rosevear from Drummond's Island.

Houghton, Houghton County.—A small amount of marl was found in making some excavations at West Houghton.

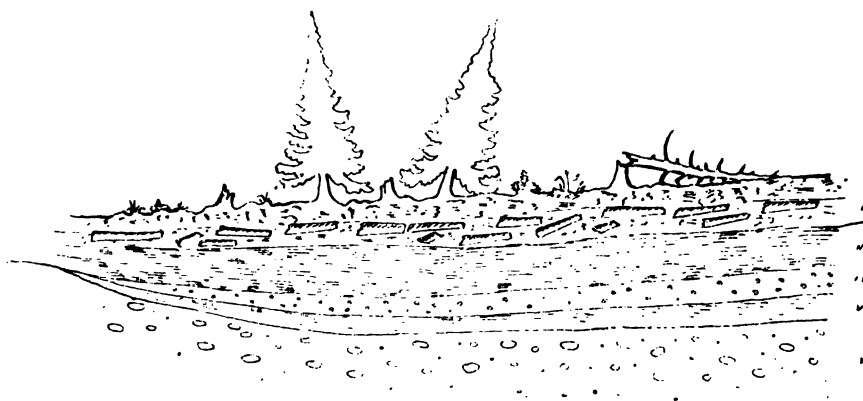


Fig. 32. Section of marl deposit at Houghton.

- I. Ordinary forest swamp surface, ground covered with grass.
- II. About 2 feet of old rotten timbers fairly well compressed.
- III. About 6 feet of very fine peat, pretty solid.
- IV. Marl full of small shells.
- V. Fine clay.
- VI. Glacial drift.

Mr. W. V. Savicki gives the section of a deposit shown in Fig. 32, perhaps the same, not far from the old Atlantic Mill, but in the thickest place exposed only about a foot thick. It was exposed in a ditch dug in 1899 for the Houghton water supply.

Mr. Geo. L. Heath made the following analysis:

The marl was first dried at 105°C. As the organic matter is determined by difference and as it is not altogether certain that the lime is combined as carbonate, or the potash and soda as carbonate instead of silicate the difference 6.81 may be less than the real amount of organic matter by a trifle.

Silica	1.85		
Iron oxide and trace of alumina	1.18		
Potassium oxide	0.27	as carbonate	0.40
Sodium oxide	0.19	as carbonate	0.32
Calcium oxide	48.88	as carbonate	87.28
Magnesium oxide	0.78	as carbonate	1.64
Calcium sulphate	1.02		
Loss on ignition, CO ₂ organic matter, etc....	46.33	difference	6.81
Total	100.50		

Concluding Remarks.

It will be easily seen that the foregoing notes are a very uneven and imperfect account of the deposits of bog lime in the State. Yet they are enough to show why they are so imperfect. Deposits of bog lime are everywhere present in the State, though most often probably in the higher parts. They are often covered by swamp, and often difficult of access, being neither water nor yet land. The resources of the State Survey are entirely inadequate to make a systematic study of them, and we have depended largely upon the investigations of private parties, incidental observations, and the hasty summer's work of Mr. Hale.

Enough has been learned to bring out some salient points, however, and show that there is no lack of marl which should be more properly called bog lime, in most of the State. It is much higher in lime, and has but few transitions to the calcareous clays, which are abundant in the State, and have just as good title to the name marl, but usually run from 30 to 40% of carbonates. Deposits of surface clays which run low in carbonates are rare, and there is usually a fair percentage of magnesia. An important exception are the clays which are but weathered shales.

I have concluded to append together instead of scattered through the text according to locations a group of analyses which are due to Prof. Delos Fall of the Board, and at the same time reprint a valuable paper which he presented to the Michigan Society of Engineers, with the permission of the Society. Other* analyses by Prof. Fall will be found scattered through the report, having been received at various times from the various parties for which he has executed them. It is apparent that he and his pupils have been connected with many of the successful enterprises in the State.

Namely: pp. 136, 154, 304, 305, 336.

MARLS AND CLAYS IN MICHIGAN.*

BY DELOS FALL, SC. D., ALBION COLLEGE.

Portland cement is a chemical compound resulting from the burning at a temperature of about 3,000 degrees Fahrenheit, of an intimate mixture of a certain definite proportion of pure limestone and clay of a definite condition and pure quality. The limestone may be of a solid and crystalline form or in a finely divided condition, in which it is found in the so-called marl beds of Michigan. The clay may be solid shale or the plastic variety that has resulted from the disintegration of the parent rock. What constitutes a pure quality for clays and marls, and what the proportion in which they are to be mixed is a question which the chemist alone can determine.

Marl.

The term "marl" from the mineralogical standpoint, is a mixture in any proportion of limestone and clay. In certain parts of our country, notably in the southern states, but not to my knowledge in Michigan, this mixture approximates very closely to the proportion required for a high grade Portland cement. As the term is used with us, it applies to a comparatively pure calcium carbonate with a certain very small proportion of clay, and it may contain a small percentage of magnesia and sulphuric acid.

Deposits of marl are found in the beds of those lakes in Michigan, which, owing to their past histories, are now surrounded by marsh lands, the marl being found in the bottom of such lakes, and extending out under the overlying muck or peat. These beds vary in depth from a few inches at the edge of the deposit to 30 or 40 feet in the center. In places they are almost entirely uncovered, and are exposed to view in such a way that they can be immediately utilized without any expense for the stripping process which must be employed in all cases where there is a covering of muck or peat. Occasionally a layer of greater or less thickness is found, consisting of decayed organic matter lying in the center of the depth of the bed, indicating that in the process of the deposition of the marl, the level

*From Michigan Engineer, 1901, pp. 124, 133.

has alternately risen and fallen. In some cases it has been found possible, by draining off the water of the lake, to uncover rich and extensive beds of marl with no other expense attached to this stage of the work. The composition of the marl in the various beds in Michigan varies to a considerable extent. One bed, which has been exhaustively examined, gives, on analysis, average of fifty samples, a composition as follows:

Silica, SiO_2 .....	.53%
Alumina, Al_2O_3 .....	.75
Iron oxide, Fe_2O_3	Trace.
Calcium carbonate, CaCO_3	96.
Magnesium carbonate, MgCO_3 .....	.09
Sulphuric anhydride, SO_3 .....	.02
Organic matter	3.09
	<hr/>
	99.90

This is extremely pure. Marl is rarely found running so high in calcium carbonate, and so low in clay, magnesia and sulphuric acid.

An average of eighty-four samples from another bed resulted in the following composition, which may be taken as fairly to represent the marls of Michigan:

Silica, SiO_2	2.08%
Iron oxide, Fe_2O_3 }	
Alumina, Al_2O_3 }	2.59
Calcium carbonate, CaCO_3	88.06
Magnesium carbonate, MgCO_3 .....	.32
Sulphuric anhydride, SO_3 .....	.78
Organic matter	5.30
	<hr/>
	99.13

Exclusive of the organic matter, the 84 samples average 93.10% of carbonate of lime.

The above bed is characterized by a strain of blue clay accompanying the marl. This is not a serious adulteration of the marl, except that it will require more constant attention from the chemist in order to produce a mixture of constant composition.

The main points of interest concerning prospective value of marl for manufacturing purposes are the proportions existing in the raw material of carbonate of lime, magnesia, sulphuric acid, and organic

matter. It is desirable that the carbonate of lime should run as high as possible, in order that there may be the largest percentage available of this, which is the most important contribution to the final composition of Portland Cement. Too much organic matter will lower the percentage of carbonate of lime, and clog the rotaries in the process of burning, and, because of this fact, will diminish the amount of the finished product which the rotary furnace is capable of producing per day. With excessive amount of organic matter present in the marl, the total output of a sixty by six rotary furnace might be as low as seventy-five or eight barrels per day, when, with the marl containing less organic matter, say from two to not more than five per cent, the product should be from 120 to 130 barrels per day.

The presence of magnesia in the cement must be considered deleterious to the quality of the cement, from the fact that it refuses to unite with the clay at the temperature required for the burning of the cement, and is left at the end of the process in the form of caustic magnesia MgO . When water is added it takes up that water to an extent which produces a hard product of increased volume, and hence produces a cracking or disintegration of the proposed structure. In general, it may be said that a percentage of not more than two per cent is not considered harmful. The presence of sulphuric acid in the marl and clay, and its effect upon the finished product, does not seem to be appreciated as it ought to be, for it is noticeable that most of the reports of chemists as to their analytical findings give no mention of sulphuric acid in the marl. The chemical analyses should always state the presence or absence of this ingredient, and the proportion in which it occurs. Sulphuric acid generally occurs in the form of calcium sulphate or gypsum, and it is well known that the presence of it in considerable percentage, say more than two per cent, retards the setting quality of the cement. At the same time, it possesses no hydraulic qualities, but will in the presence of water partially dissolve and thus lead to the final disintegration of the proposed structure.

Michigan Clays.

Originally it was supposed that the difficult problem for the initiation of a Portland Cement industry was to discover sufficiently large beds of pure marl; indeed, it is true that that feature of the problem is not so easy a task as many suppose, the number of beds

in Michigan being somewhat limited as to quantity, accessibility, and quality. On the other hand, it was supposed that an inexhaustible supply of clay of proper quality could be found adjacent to any marl bed. Farmers and others would point to large deposits of clay which they were sure would prove of sufficient purity and quality for the purpose. By this general tradition, promoters and investors have been led into the establishment of large plants, only to find that they must seek long and sometimes unsuccessfully for clay of the proper material. Not all clay will make a good Portland Cement.

Clay is essentially a silicate of aluminum but rarely occurs without the admixture of iron oxide, calcium carbonate, or sulphate, and sometimes magnesia. While calcium carbonate must be used in the mixture for cement making, its presence in the clay complicates to a large degree the problem of the chemist in making that mixture, and more especially maintaining the mixture in a uniform and constant composition. Many of our clays run too high in alumina, making, upon burning, a quick setting cement, not so durable and permanent as that produced from a clay containing a less amount of alumina. The following analysis of a Michigan clay will aptly illustrate this point:

Silica, SiO_2	60.14
Alumina, Al_2O_3	20.73
Iron oxide, Fe_2O_3	5.18
Lime, CaO	1.19
Magnesia, MgO} .....	.44
Sulphuric anhydride, SO_3	3.35
Loss on ignition	8.16
	<hr/>
	99.15%

This analysis illustrates another bad feature existing in some Michigan clays, namely, the too large percentage of sulphuric acid.

The 3.35 per cent of sulphuric anhydride present in this clay represents 5.6 per cent of calcium sulphate, and this in the mixture with marl would bring the percentage very near to two per cent, which might be considered to be the limit permissible for that ingredient. The analysis above given would be almost ideal if the alumina ran at from six to ten per cent, and the SO_3 was lower or altogether absent.

Clays should contain very little free sand, iron oxide, or organic matter. It should have a tendency to gelatinize when treated with

acids. The silica must be combined and not free, for the reason that at the temperature at the command of the cement-maker, free silica will not combine to form a silicate of lime which is the essential ingredient in Portland cement. About sixty per cent of the clay should be silica.

Three classes of clay found in Michigan are illustrated by the following analyses from my laboratory note book:

	No. 1.	No. 2.	No. 3.
Silica, SiO_2	49.36	60.70	71.84
Alumina, Al_2O_3	10.30	20.92	15.53
Iron oxide, Fe_2O_3	3.90	7.06	3.57
Cal. car., CaCO_3	31.01	.73	.75
Mag. car., MgCO_3	1.77	None.	Trace.
Sul. triox., SO_3	3.15	.60	1.24
Organic matter	1.00	9.89	5.68
	<hr/> 100.49	<hr/> 99.90	<hr/> 98.61

No. 1 possesses the great disadvantage of a variable quantity of calcium carbonate, the fact that the relation of this to the clay itself is that of a mere mixture growing out of accidental and therefore varying conditions making it very certain that no two samples of the same bed would show the same composition. The clay is also imperfect from the presence of a high percentage of calcium sulphate. The temperature at which proper calcination would take place can scarcely be inferred, but it would probably be high. Clay No. 2 is a good clay; it will burn at low temperature and be economical of fuel. It is rather high in alumina and would make a quick setting cement. Its setting quality could be retarded by the addition of a small percentage of gypsum.

Clay No. 3 is too high in silica; the temperature required for the calcination would necessarily be very high, the excessive temperature being hard to acquire and very disastrous to the life of the rotary.

Discussion.

Mr. Lane.—There are many kinds of marl in the State,—one kind and another, and the question of clay is an important one. One advice I should give—if I were to give advice—would be to call in the services of a chemist; but before starting to get your chemist, it might be well to make a few preliminary tests yourself. Now

there are two simple tests, which, if applied might prevent two-thirds of the samples sent to my office from ever being sent. In the first test, if you can feel grit when you chew the clay, feel the clay in your teeth, probably it is not worth investigating. In the second place testing it with hot acid, if there is a good deal of lime, it is likely to mean more or less magnesia, and certainly a good deal of trouble for the chemist. Ordinary vinegar or anything hot and sour, is not bad to test it with, if you happen to be in the woods. These two tests will rule out a good many clays. Another point is the question of coal to be used, which certainly is important. I think there is Michigan coal that ought to be good enough to answer the purpose. I have seen samples of Michigan coal, taken from near Saginaw, which show very little ash and very little sulphur, and I think ought to be quite good.

Professor Campbell.—I will say that in our own work here we have undertaken in the past couple of years to do a little work on cement, though our experiments have not taken us far enough along to draw any reliable conclusions. We are trying to study a few of the conditions which exist. In the course of that we have analyzed a number of samples of clay and marl, and in the synthetic work that we are trying to do, we are trying to control the different factors which determine the property of the cement. The chemical composition is only one. It is well known that the proportions are very close between the different elements which have to be maintained in the mixture, but this is only one of the various factors which we are working on. One factor is the time limit, the time for which the material is subjected to a given heat, say 2,300 degrees Fahrenheit, will give the same result as a shorter time at 2,700 or 2,900 degrees.* These are some of the problems on which we are trying to throw a little light; but it will be necessary to make long-time tests. One of the great troubles that we find in studying the tests that are made, is the short-time tests that are used in making cement tests. They are usually from 24 hours to 28 days, most of them not exceeding 28 days in time, which seems like nothing to me to determine the property of cement. We have had a few from three to six months, and a year, and some that we had kept longer. Cement will change very much after three months, and after six months. We have had cement that would gain steadily up to three months, then drop off at six months, after that gain again, so it is almost impossible to draw conclusions from a short-time test. Now

*See "Some preliminary experiments upon the clinkering of Portland Cement," by E. D. Campbell, *Journal Am. Chemical Society*, Vol. XXIV, No. 10, Oct. 1902.

this question of magnesia is a vital one. In one case, for instance, we have made cement with as high as 6.90 per cent and after six months' test, the cement has been gaining with no signs of deteriorations as yet. Whether this will continue, or whether it will commence to deteriorate after a year or two, time will tell. I do not feel like expressing much of an opinion on the clay that is best adapted to cement work, because the longer we work on it, the less I feel we know or are able to pass an opinion on. I have had occasion two or three times to change my own opinion after working awhile. While some experiments will lead to the idea that clay should have a certain proportion of aluminum, silica, etc., other clays that at first are thought to be not at all satisfactory will give equally good results. So I do not feel like expressing my opinion very strongly as to what an ideal clay or marl should be.

Mr. Lane.—I would like to ask if you have made any experiments as to the influence of the fineness of grinding.

Professor Campbell.—We always try to grind to the same degree of fineness and test the fineness. To give an idea of a single property of the cement, the time of setting, for instance. I think there are not less than six different factors that determine the time of setting, and every one of these may vary, so that it is hard to get at the exact benefits of a single factor. It will undoubtedly be years before we can get at the true nature of what cements are, and the influence of the different factors on the properties of cement. Portland cement is extremely sensitive to water, and quite a difference will be produced by the addition of a little water.

Mr. Russell.—By the addition of a little water when you have reached the turning point, it is remarkable how the strength runs down. The man who works for a dollar a day says, "Turn on more water," and "That is enough" and it is impossible to induce people to see that their structure would be very much better if they would understand that there were quantitative relations between the water and the cement, and that they might learn that lesson from those who are able to give it, and their work would be very much bettered by it.

Mr. Brigden.—What is the least amount of water possible to make a good mixture?

Mr. Russell.—Well, you can work with a trowel a neat cement with something like 22 per cent, can you not, Professor Campbell?

Prof. Campbell.—That is as low as you often get. If you go much beyond that, say 23 per cent, it will run the tensile strength down to a remarkable degree and impair the structure.

Mr. Brigden.—I think the man with the hoe has the better end of the argument in almost every case, whether the work is done by the contract or by the day; you can stand and watch him, and you will occasionally hear from the bottom of the trench, "This is too stiff," or "This is too wet," etc. I know but little about the matter of cement or its development. I can hardly understand what Mr. Greene meant when he said there seemed to be a large opening for the manufacture of water pipe from cement. I had supposed, and I think I have good authority for that supposition, that the use of cement-lined pipe (if that is what he means) was going entirely out of date, and that cast iron was used for water mains, and I think that is true of every portion of the United States east of the Mississippi River.

Mr. Rogers.—I would like to ask Prof. Campbell something about the practical methods for the engineer to determine whether there is too much magnesia in the cement or not, if he has only a few days or a month or so to test the cement before he has to use it.

Prof. Campbell.—I cannot give a method that would be entirely satisfactory, because a great many of the difficulties that are often attributed to magnesia in the way of expansion, I think are not due to magnesia at all; so I do not as yet think there is any entirely satisfactory test. Of course, the chemist's analysis will show the per cent of magnesia in the cement; but then the old question comes up again as to what per cent is allowable. That is the question that we are working on at the present time.

Mr. Whitney.—In regard to this question of mixing cements, I think one feature that is often overlooked, and it may be because of the contractor's haste or tendency to save, is that long mixing has a good deal to do with the strength of the cement, that is, after the water is put on to the cement and mixed with the sand, the mixture grinds the cement finer and makes the water appear milky, and when that condition prevails, you will find the strength of the cement is a great deal more. I want to say a word about marl beds. I have had some experience the last two years, and have probably made something like fifteen hundred soundings. In the question of sounding marl beds, there are two or three points of interest that may be brought out. They vary as to their depth where sometimes we would least expect it, and the bottom of them is so irregular

that sometimes it is necessary to take soundings quite close together. Another thing is that there is a good deal of difference in the appearance of marls. Some will be yellow as ordinary corn meal, and very mealy and be very poor marl, and there will be some that is nearly white, and some that you will first feel like throwing out, when, upon a careful examination, you will find that it is pure marl, but not so finely disintegrated. Then again you will run across sand that is a little closer to the surface than you hoped to find it, and you have got to be rather particular to know when you strike it. Often you will find marl in the condition of nodules*, and the person sounding will be almost sure he has struck gravel; he can hear it grate, and it is almost impossible to turn an augur through it; it takes a pretty good job of well-driving, sometimes, to get through a small layer of it. There is one other fact I might mention, that of course would be easily observed, and that is that around the mouth of streams flowing into lakes where there are marl deposits, there is apt to be a layer of organic matter over the marl, sometimes very deep, sometimes quite deep, and sometimes mixed with the marl and extending quite a way. I would also say that in sounding with augurs, it is sometimes quite desirable to have two sizes of augurs, as there is often a good deal of suction which pulls off the material at the bottom, and gives you, when you pull it up, the material from the top. Of course the use of a go-devil is something by which you can take up samples from any depth, and is quite valuable. Where there is a mixture of clay it is quite apt to be found toward the bottom, and one can rapidly detect it by the color or by the feeling or the appearance of the augur when it is pulled up, and of course the per cent of clay can be actually determined by a chemical analysis.

* Probably Schizothrix, elsewhere described, p. 90.

CLAY ANALYSES.

Analyst.	Delos Fall.		A. N. Clark.	Fall.
No.	601 to 604	822	.....	635
SiO ₂ , Silica.....	62.65	69.72	69.00	75.10
Alumina.....	23.06	18.96	15.16	12.35
Iron oxide.....	6.82	1.29	5.00	8.21
				1.13
Calcium as oxide.....	1.02	.40	.80	.....
Magnesium as oxide.....	.11	tr.	3.36	.....
Sulphuric anhydride.....	4.23	1.13	.....	2.42
Organic matter.....	2.22	.....	.....	.....
Difference.....	.....	7.76	6.68	.....
	100.11	99.26	100.00	99.21

Nos. 601 to 604 represents the average of 4 clay samples, from near Athens.
 No. 822. Jackson, probably a coal measure shale clay, rather too high in silica.
 An analysis by Mr. Clark.
 635. Kalamazoo county clay.

MARL ANALYSES.

Analyst. Delos Fall.			
No.	327 to 424	819	820
SiO ₂.....	.53	.58	.60
Alumina.....	.754	.76	.70
Calcium as oxide.....	52.61	.....	.....
as carbonate.....	(93.91)	94.75	75.06
Magnesium as oxide.....	20.90	.09	tr
as carbonate.....	(1.88)	.....	.....
Sulphuric anhydride.....	.....	.62	1.24
as calcium sulphate.....	.....	.....	.....
P ₂ O ₅.....	.....	.....	.....
Organic matter and carbon dioxide.....	42.28	.....	.....
Water.....	.....	.....	.....
Difference.....	3.12	.....	.....

Nos. 327 to 424 is an analysis representing the average of 14 samples from Lime Lake.
 Nos. 819 and 820 represent the average of 25 borings at Spring Arbor, the Pyramid Portland Cement Co. location.

MARL ANALYSES.

Analyst. Delos Fall.							
No.	425	426	427	428	506 to 886	740	743
Silica.....	2.658	.371	.332	.452	2.08	.645	.61
Alumina.....	2.664	.721	.729	1.563	2.59	2.22	1.90
Calcium as carbonate.....	86.373	84.973	86.439	89.675	88.06	94.18	93.81
Magnesium as carbonate.....	tr.	tr.	tr.	.50	.32	.234	.19
Sulphuric anhydride.....	.....	.....	.....	.....	.78	.201	.22
Organic.....	.....	.....	.....	.....	.....	.....	.....
Water.....	8.851	13.935	12.001	8.31	5.30	.....	.....
Difference.....	.....	.....	.....	.....	.....	.....	.....
	100.040	100.000	99.501	100.500	99.13	97.480	96.73

Nos. 425 to 428 are from Goose Lake. See p. 233.
 Nos. 506 to 886 represent the average of analyses of 84 samples from Athens, T. 4 S., R. 8 E.; the iron included with the alumina.

MARLS AND CLAYS IN MICHIGAN.

353

FISH LAKE MARL ANALYSES.

Analyst. Delos Fall.									
No.	688	689	690	691	692	693	694	695	
Insoluble SiO ₂.....	.54	.77	.41	.38	.26	.22	.06	.24	
Alumina.....	.82	.64	.38	.60	.38	.55	.5	.54	
Iron.....	tr.	tr.	tr.	tr.	tr.	tr.	.....	.....
Calcium as carbonate.....	94.33	949.4	93.35	95.42	94.21	98.86	92.12	90.52	
Magnesia.....	none	none	none	none	none	none	none	none	
Sulphuric anhydride.....	1.12	.87	.44	.87	.80	.75	1.10	.82	

KALAMAZOO COUNTY MARL ANALYSES.—Nos. 622 to 638, except 635.

Analyst. Delos Fall.									
No.	622	624	625	926	627	628	629	630	
Insoluble Silica.....	3.47	.82	1.68	2.38	1.70	2.40	1.86	1.33	
Alumina.....	3.32	.34	1.95	1.25	3.04	2.46	2.60	3.52	
Calcium carbonate in Ing marl.....	90.22	.....	92.52	92.55	91.19	94.15	.....	.....
as carbonate.....	80.93	92.11	92.47	88.16	87.33	86.84	92.21	91.88	
MgO.....	tr.	.8	.0	.0	.07	.0	.0	tr.	
SO ₃	1.96	.8	1.39	.75	1.29	3.52	1.26	1.82	

Analyst. Delos Fall.									
No.	631	632	633	634	.....	636	6.37	6.38	
Insoluble Silica.....	1.36	.58	3.4 clay	1.64	.....	1.16	3.21	3.61	
Soluble Silica.....	2.10	.90	4.05	1.95	.....	2.40	4.07	4.04	
Alumina.....	.....	.....	.....	.....	.....	.....	.....	.....
Iron oxide.....	tr.	.....	.....	.....	.....	.....	.....	.....
Calcium as oxide.....	.....	.....	.....	.....	.....	.....	.....	.....
as sulphate.....	.....	.....	.....	.....	.....	.....	.....	.....
as carbonate.....	91.26	92.84	88.98	88.28	.....	91.86	88.18	90.77	
Magnesium as oxide.....	.....	.....	.....	.....	.....	.....	.....	.....
as carbonate.....	.....	0.	mere trace	0.	.....	0.	0.	0.	
Sulphuric anhydride.....	.96	2.11	1.40	1.36	.....	1.53	4.49	2.02	

CHAPTER X.

METHODS OF, AND COMMENTS ON TESTING CEMENT.

BY RICHARD L. HUMPHREY.

Structures of masonry or concrete owe their stability almost entirely to the character of the substance which binds or cements together the brick, stone, and other materials used in their construction.

From the earliest times, therefore, there has been an almost constant endeavor to obtain some material which would attain great strength in a very short period of time and which would resist the forces which tend to disintegrate or decompose it. Such a material must harden rapidly, equally well in air or water and have great adhesive qualities.

The material used in the earlier structures consisted of a mixture of sulphate of lime (gypsum) and sand (the latter usually of a volcanic origin) or a mixture of lime and volcanic ash or trass and sand.

Such mortars required considerable time to harden and also protection during the initial stage of hardening from rain and frost, which readily dissolved and disintegrated them.

It was necessary therefore to frequently renew the mortar in masonry by pointing, unless sufficient carbonic acid had been absorbed from the air to convert the lime into a carbonate, in which form it offered greater resistance to the weather.

This material proved very unsatisfactory even when carefully used and protected from the weather during the early stages of hardening, and at best was only meagrely hydraulic.

The most satisfactory results were obtained with Roman Cement, a mixture of fat lime and a volcanic ash. With the downfall of the Roman Empire the art of making this cement was lost and subsequent experimenters endeavored to recover and to equal or excel this Roman Cement. As these efforts became fruitful of results and the quality of the mortar improved, it became necessary to de-

vise some means by which the relative value of different mortars could be determined.

The present system of testing may be said to have begun with the experiments of John Smeaton in 1756, in connection with the rebuilding of the Eddystone Lighthouse. Smeaton in his endeavors to obtain a cement which would harden under water made cements from various materials and tested their hydraulic qualities by immersing small pats or cakes, made of the cement, under water.

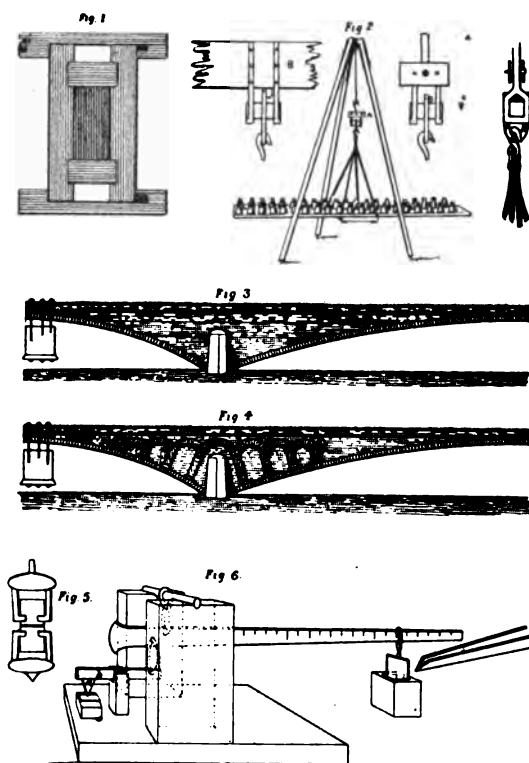


Fig. 33. Apparatus for determining the adhesive strength of mortars.

Later Pasley measured the adhesive qualities of mortars by sticking two bricks together and determining the force required to pull them apart. See Fig. 33 (2).

He also determined this same property by building out from a wall, horizontally, as many bricks as possible in a given time. See Fig. 34 (1).

* In accordance with our custom all illustrations printed with the text are figures. In this paper a number of the figures are reduced from plates containing a number of figures, the numbers referring to which are placed in parentheses

This test was more properly a test for determining the rate of setting.

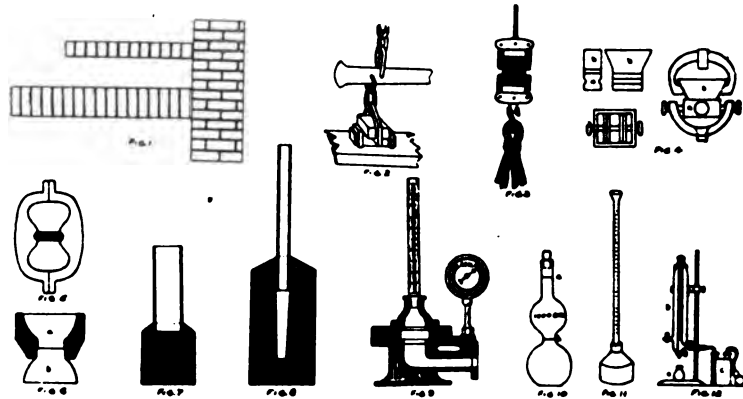


Fig. 34. Illustrations of apparatus in cement tests.

Vicat gauged the relative hardness of his mortars by measuring the penetration of a weighted needle falling from a given height.

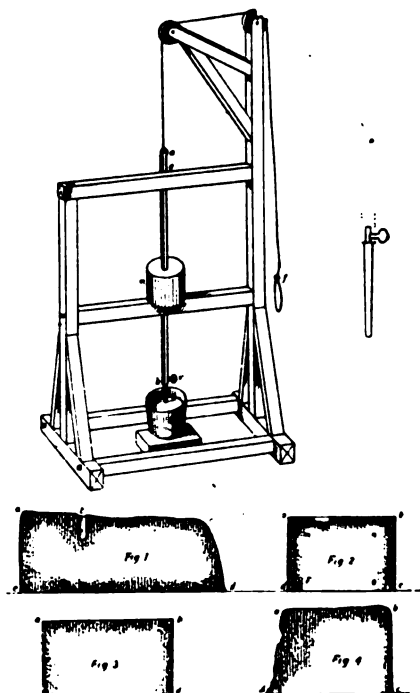


Fig. 35. Vicat needle as originally designed.

The apparatus which he devised for this purpose is shown in Fig. 35.

It was not, however, until 1858 that a definite system for testing was evolved. In that year John Grant, the Engineer in charge of the London Main Drainage System proposed the tests by which the cement used in this work was inspected.

This marked the beginning of systematic tests of cement. The evolution from these few simple tests has been rapid; at present there are numerous tests in use, all more or less rational, many impractical and none entirely satisfactory.

It is to be noted, however, that the extreme methods formerly in vogue are becoming less used, and the better informed engineers are adopting less radical and more simple tests.

During this period in the development in the methods for making tests, the manufacturer has been forced to meet tests of constantly increasing severity. As a result the quality of the cement, particularly of the American Portland, has been so greatly improved that today the manufacturer is able to produce a material, capable of attaining great hardness in a few hours and exceeding in a few months the strength attained by ancient mortars after 2,000 or more years.

Indeed the quality of the modern Portland Cement has improved so considerably that it has engendered a greater confidence on the part of the Engineer, resulting in a rapid extension of its field of usefulness. So great is the varied application of cement in construction that some one has truly said, "We are on the threshold of the Cement Age."

In Fig. 44 is shown the relative strengths of the modern high grade Portland Cement, cement of the time of Grant, common lime mortar etc., which illustrates the marked superiority of the modern cement.

While it is true that the quality of cement has been vastly improved, the methods for making the tests are still crude and leave much to be desired. Nor are the tests sufficiently defined to enable the novice to follow them with satisfactory results. It is only after considerable experience that sufficient skill is acquired which permits of even approximately satisfactory results.

To define a system of testing which will serve as a reliable guide for novice and expert alike in determining the qualities of cement is a problem of no little difficulty.

The object in testing cement is first to ascertain whether the quality is up to a certain prescribed standard (the specifications), and second for purposes of research.

The inspection and testing of cement is an art requiring considerable experience and much skill. The difficulty in making the tests lies almost wholly in the "personal equation" of the person who makes the tests, a variable which renders the results of such tests not only relative but inaccurate.

Another difficulty in the inspection of cement is the fact, that a cement having passed satisfactory tests at the place of manufacture is no guarantee that the cement will yield the same or even as satisfactory tests at the place of consumption, even should the same person make the tests. From the moment the clinker is reduced to an impalpable powder until it is made into a mortar or concrete and becomes a part of the structure, its physical and chemical properties are constantly undergoing changes which affect its value as a building material. It is doubtful whether these changes ever cease. The cement being to a greater or less extent affected by external influences tending to decompose the mass or by internal influences tending to disintegrate it.

The selection of methods for testing is not so easy as it would at first appear. The system should not depend on cumbersome methods or expensive apparatus. The number of tests should be few and simple in execution.

The inspection of cement may be divided into two classes (1) the mill tests or those made at the place of manufacture, and (2) tests of acceptance or those made at the place of consumption. The latter can be further subdivided into field and laboratory tests.

In the first class are those made by the manufacturer to check the quality of his product and are usually as severe as it is possible to make them, especially as regards constancy of volume.

This is due to a desire on the part of the manufacturer to thoroughly test the quality of his cement before it is shipped.

The methods for making the tests in both classes are, however, the same. The tests in general use are for the determination of fineness, time of setting, tensile strength, neat and with a standard sand, for 24 hours, 7 and 28 days, together with the cold water pat test, and some form of accelerated test, usually the so called "Boiling test." In addition to these, the determination of specific gravity and a chemical analysis of the finished product are made

at the mill at regular intervals; most mills make at least one complete analysis of the product each day in order to check the composition.

Where analyses are required on work not possessing the requisite facilities they should be made by some well established chemical laboratory.

While the methods used by the consumer or manufacturer are the same the number of tests made are modified to suit the time available for the purpose and the facilities.

The standard for gauging the results of the tests of acceptance for determining the value of a cement for the purposes for which it is to be used is the specifications. The requirements of this specification should be based on the results obtained by the persons who make the tests. Before fixing these requirements it should be first ascertained what results can be obtained from well known brands of cement by the persons making the tests. Upon these results should be based the requirements of the specifications.

The scope of the tests to be made will depend on the facilities and the importance of the work. In permanent laboratories the testing should be systematic and thorough. Such a system will now be described in more or less detail, indicating where it may be modified to suit other conditions.

SAMPLING.

The selection of the sample from which the tests are to be made while apparently a very simple matter is one of considerable importance and should therefore be carefully done.

At the time of sampling a note should be made of the condition of the cement, i. e., whether cement is lumpy, caked or otherwise damaged.

The sample should be taken from the heart of the package as the outer portion is sometimes more or less impaired.

About one barrel in every ten should be sampled.

Where the cement is delivered in barrels the sample can be drawn through a hole made in one of the staves midway between the heads by means of an auger or sampling iron similar to the ones used by sugar inspectors, Fig. 36 (9.) if the shipment is in bags, the sample is taken from the heart of the package with the hand, or a scoop.

When the sample is taken at the place of manufacture it should be done regularly as it comes from the mill and goes into the bin.

Where cement is held in storage pending the result of the tests, it should be protected from the weather, in order to prevent its being damaged.

The samples should be passed through a sieve having twenty or thirty meshes per lineal inch in order to remove the lumps and foreign matter. This is also a very efficient means of mixing the individual samples in case an average sample is desired; where time will permit, the individual samples should be tested separately in addition to the test on the averaged samples.

CHEMICAL ANALYSIS.

Systematic chemical analyses of cement should be made in all permanent laboratories, not with a view of eventually introducing into specifications chemical requirements (other than those for sulphuric acid and possibly magnesia) but in order that we may have some data pertaining to the composition of the cement when studying the results of the long time tests.

Chemical analyses are chiefly valuable to the manufacturer. The determination of silica, of iron and alumina and of lime is of little value as an indication of quality. They furnish valuable aid in detecting adulterations with inert material in considerable quantity and in determining the quantity of certain deleterious constituents as magnesia and sulphuric anhydride.

The following scheme of chemical analysis is recommended:

One half gram of the finely pulverized sample, dried at 100° C., is thoroughly mixed with four or five times its weight in sodium carbonate, and fused in a platinum crucible until carbon dioxide, CO_2 , no longer escapes; the crucible and its contents is placed in a beaker and twenty or thirty times its quantity of water, and about 10 cubic centimeters of dilute hydrochloric acid (HCl) is added; when complete solution is effected, it is transferred to a casserole and placed on a water bath, and evaporated to dryness several times. The mass is taken up with dilute hydrochloric acid, HCl , and water, heated for a short time and filtered, washing the residue on the filter thoroughly with hot water. The filter is dried, ignited and weighed. This weight (less ash) gives the amount of silica, SiO_2 .

The filtrate is brought to boiling, and ammonia is added in slight excess; the boiling is continued until the odor of ammonia is no

longer perceptible. Filter and wash, re-dissolve in hot dilute HCl, again precipitate with ammonia and filter through the previous filter and wash with boiling water. The precipitate dried, ignited and weighed, less ash gives the amount of alumina, Al_2O_3 , and ferric oxide, Fe_2O_3 .

The iron is determined volumetrically by fusing the ignited precipitates of alumina and iron with de-hydrated potassium sulphate in the platinum crucible, it is then dissolved in sulphuric acid and titrated with potassium permanganate.

The filtrate from the iron and alumina is heated to boiling, and boiling ammonium oxalate is added until a precipitate is no longer formed. After boiling for a few minutes it is set aside for a short time, when the precipitate has settled perfectly, decant the clear liquid through a filter, wash by decantation, dissolve the precipitate in hot dilute hydrochloric acid, HCl, using as small a quantity as possible to effect a complete solution; heat to boiling and add ammonia, heat on a water bath for a few minutes; when the solution clears filter through the previous filter, wash thoroughly with hot water. Dry the precipitate, ignite to constant weight, and weigh as CaO; or dissolve with sulphuric acid and determine the lime volumetrically by titration with potassium permanganate of a known strength.

The thoroughly washed precipitate of calcium oxalate is dissolved in hot dilute sulphuric acid and the solution is titrated with standardized potassium permanganate.

The filtrate from the calcium oxalate is made alkaline with ammonia and 30 cubic centimeters of solution of hydro-disodium phosphate is added; the whole is set aside in a cool place for twenty-four hours; it is then filtered and washed about fifteen times with ammonia water solution (1:5). Dry the precipitate on the filter, brush on to a large watch glass, burn filter on the lid of the weighed crucible. When the carbon is consumed transfer the precipitate to the crucible and ignite to dull redness, keeping the crucible covered. If the precipitate is not perfectly white on cooling, moisten with a few drops of nitric acid, evaporate and ignite to dryness; weigh as magnesium pyrophosphate and calculate to MgO.

Sulphuric acid.—This is determined in a separate portion. Weigh out about five grams and treat as in the regular analysis, separating the silica; the filtrate is heated to boiling, acidulated

with hydrochloric acid, and boiling barium chloride is added; the boiling is continued for ten minutes; when the precipitate has subsided, filter. The precipitate is thoroughly washed in hot water, dried, ignited and weighed as barium sulphate and calculated to sulphur trioxide, SO_3 .

Carbonic acid.—This can be determined with sufficient accuracy by means of the ordinary extraction apparatus.

For routine work where quick results are desired the above scheme may be shortened in the following manner:

The first solution may be effected by treating the finely pulverized sample with concentrated HCl diluted with an equal portion of water to which a few drops of concentrated HNO_3 has been added. Evaporate to dryness on the sand bath until all odor of HCl has disappeared. The residue is then treated with concentrated HCl boiled a few minutes diluted with water and filtered. The silica is separated by filtration and ignition as above, or the residue after taking up and boiling with concentrated HCl can be treated with sodium carbonate and the solution effected with concentrated HCl and water as above described.

While other short cuts could be suggested, it is not deemed advisable since the saving in time is not commensurate with the accuracy.

SPECIFIC GRAVITY.

The determination of specific gravity or true density is of questionable value except in the hands of an experienced operator.

In as much as the differences in the results are very small, considerable care must be exercised to obtain accurate determinations.

It is perhaps useful in detecting underburning or adulteration with material of low specific gravity. The adulteration must, however, be in considerable quantity in order to materially effect the results.

A better means of detecting adulteration is through the use of a liquid of heavy gravity and not capable of affecting the cement.

Le Chatelier's apparatus is the best means for making determination of specific gravity.

This apparatus consists of a flask D Fig. 36 (3) of 120 cubic centimeters capacity, the neck of which is about 20 centimeters long. In the middle of this neck is a bulb C, above and below which are two marks engraved on the neck, the volume between these marks,

E and F, being exactly 20 cubic centimeters. Above the bulb the neck is graduated into 1-10 cubic centimeters. The neck has a diameter of 9 millimeters. Benzine free from water is used in making the determinations.

The specific gravity can be determined in two ways: (1) The flask is filled with benzine to the lower mark E, and 64 grams of powder are weighed out; the powder is carefully introduced into the flask by the aid of the funnel B. The stem of this funnel descends into the neck of the flask to a point a short distance below the upper mark. As the level of the benzine approaches the upper mark, the powder is introduced carefully and in small quantities at a time until the upper mark is reached. The difference between the weight of the cement remaining and the weight of the original quantity (64 grams) is that which has displaced 20 cubic centimeters. (2) The whole quantity of cement is introduced, and the level of the benzine rises to some division of the graduated neck. This reading + 20 cubic centimeters is the volume displaced by 64 grams of cement. The specific gravity is then obtained by dividing the weight in air by the displaced volume.

The flask, during the operation is kept immersed in water in a jar A, in order to avoid any possible error due to variations in the temperature of the benzine. The cement in falling through the long tube completely frees itself from all air bubbles. The results obtained agree within .02.

FINENESS.

The degree of final pulverization which the cement receives is exceedingly important. It has been found that the coarser particles in cement are inert and have no hardening qualities. The more finely a cement is pulverized, all other conditions being the same, the greater will be its cementing properties or what is usually known as its "sand carrying" capacity.

The test for fineness consists in determining the percentages of grains of certain sizes. By our present methods this is accomplished by separating the particles with standard sieves.

These sieves are of brass wire cloth having a circular frame 6 to 10 inches in diameter about 2½ inches high and usually provided with a top cover and bottom pan, figure 36 (8.)

What are known as the No. 100 and No. 200 sieves are generally used. These sieves should have theoretically 100 and 200 meshes

per lineal inch and the wire should have diameters of .0045 inch and .0023 inch respectively. As it is impossible to obtain sieves having exactly this number of meshes on account of the impossibility of weaving the wire cloth with sufficient uniformity by hand methods, the specifications should state the approximate number of meshes and the size of the wire of the sieves to be used in making the tests.

The sample for sieving should be thoroughly dried at a temperature of about 212° F., since in this condition the cement sieves much more readily. One hundred grams make a very convenient quantity to sieve.

The manner in which the sieving is done determines to a large extent the time required for the operation. After the fine flour has passed through the sieve the coarser particles pass through very slowly; and since the final operation determines the fineness, it is important that it should be done thoroughly.

The cement is best sieved by moving the sieve forward and backward with one hand in a slightly inclined position and striking the side of the sieve gently with the palm of the other hand at the rate of about 200 strokes per minute.

The cloth of the sieve should be carefully watched, as it is liable to break and produce abnormal results.

The introduction of large pebbles or gravel, retained on a screen having ten meshes per lineal inch, into the sieve, accelerates the operation of sieving.

The sieving can be considered complete when not more than one tenth of one per cent passes through the sieve after one minute of continuous sieving.

NORMAL CONSISTENCY.

The percentage of water to be used in making tests of setting, briquettes and pats is of the greatest importance, for upon this depends the results obtained. The paste used in these tests should be of definite or what is called a standard consistency. The same consistency should be used for all tests.

The best consistency is one so wet that mortar cannot be compressed in molding and not so wet as to make a sloppy test piece which would shrink.

The best method for estimating the proper percentage of water to be used is by means of the Vicat apparatus.

This apparatus illustrated in Fig. 36 (1), consists of a frame K, bearing the movable rod L, having the cap A at one end, and the piston B, having a circular cross-section of 1 centimeter diameter at the other. The screw F holds the needle in any desired position. The rod carries an indicator which moves over a scale (graduated to centimeters) attached to the frame K. The rod with the piston and cap weighs 300 grams; the paste is held by a conical hard rubber ring, I, 7 centimeters in diameter at base, 4 centimeters high, resting on the glass plate J, 15 centimeters square.

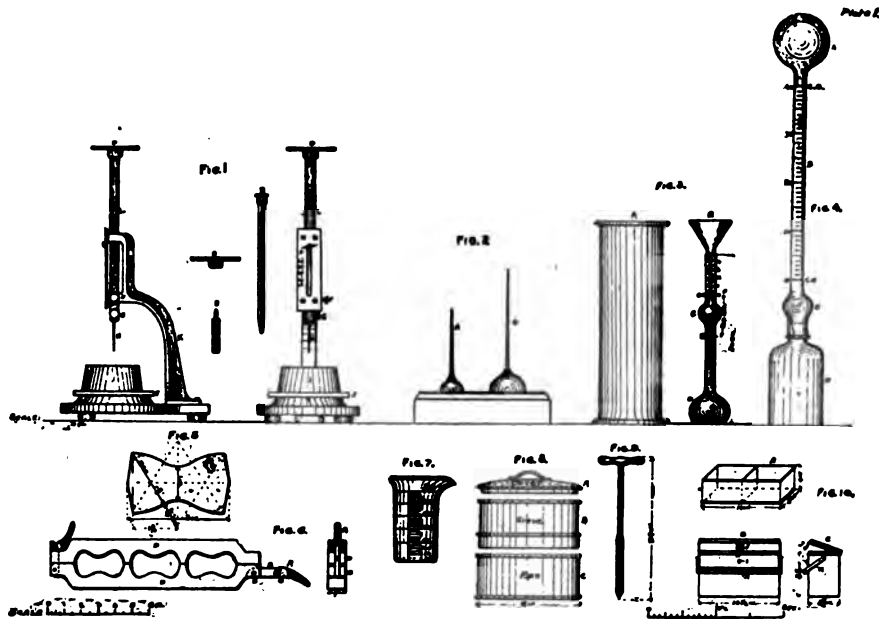


Fig. 36. Modern form of Vicat needle and other testing apparatus for Portland Cement.

Trial pastes are made with varying percentages of water. The paste is of proper consistency when the piston gently applied to the surface of the paste (confined in the hard rubber ring) sinks to a point a given distance above the upper surface of the glass plate J. (about 28 mm.).

Having determined the requisite percentage of water for neat pastes the percentages required for sand mixtures can be determined from the following table:

PERCENTAGES OF WATER FOR STANDARD MIXTURES.

Neat.	1 to 1.	1 to 2.	1 to 3.	1 to 4.	1 to 5.
15%.....	11.0	9.3	8.5	8.0	7.7
16%.....	11.3	9.6	8.7	8.1	7.8
17%.....	11.7	9.8	8.8	8.3	7.9
18%.....	12.0	10.0	9.0	8.4	8.0
19%.....	12.3	10.2	9.2	8.5	8.1
20%.....	12.7	10.4	9.3	8.7	8.2
21%.....	13.0	10.7	9.5	8.8	8.3
22%.....	13.3	10.9	9.7	8.9	8.4
23%.....	13.7	11.1	9.8	9.1	8.5
24%.....	14.0	11.3	10.0	9.2	8.6
25%.....	14.3	11.6	10.2	9.3	8.8
26%.....	14.7	11.8	10.3	9.5	8.9
27%.....	15.0	12.0	10.5	9.6	9.0
28%.....	15.3	12.2	10.7	9.7	9.1
29%.....	15.7	12.4	10.8	9.9	9.2
30%.....	16.0	12.7	11.0	10.0	9.3
31%.....	16.3	12.9	11.2	10.1	9.4
32%.....	16.7	13.1	11.3	10.3	9.5
33%.....	17.0	13.3	11.5	10.4	9.6
34%.....	17.3	13.6	11.7	10.5	9.7
35%.....	17.7	13.8	11.8	10.7	9.9
36%.....	18.0	14.0	12.0	10.8	10.0
37%.....	18.3	14.2	12.2	10.9	10.1
38%.....	18.7	14.4	12.3	11.1	10.2
39%.....	19.0	14.7	12.5	11.2	10.3
40%.....	19.3	14.9	12.7	11.3	10.4
41%.....	19.7	15.1	12.8	11.5	10.5
42%.....	20.0	15.3	13.0	11.6	10.6
43%.....	20.3	15.6	13.2	11.7	10.7
44%.....	20.7	15.8	13.3	11.9	10.8
45%.....	21.0	16.0	13.5	12.0	11.0
46%.....	21.3	16.1	13.7	12.1	11.1
Cement.....	500	333	250	200	167
Sand.....	500	666	750	800	833

$E = 2.3 N A \times 60$ where

N=weight of water (in grams) required for 1,000 grams of neat cement.

A = weight of cement (in kilograms) in 1,000 grams of sand mixture.

E = weight of water (in grams) required for sand mixture.

TIME OF SETTING.

The determination of the time required for a cement to set or the time which elapses before the paste ceases to be fluid and plastic is of considerable practical importance. The beginning of this state is called the "initial set" and the moment when the paste

offers a given resistance to change of form is called the "hard set." After the cement has set the process of crystallization or hardening begins.

To add water and again mix a cement which has set is called "retempering." As a cement loses a great deal of its initial strength by "retempering" it is necessary to determine the length of time required for the cement to set in order to avoid "retempering" the mortar on the work.

Tests for the time of setting are made on pastes of neat cement only, as in sand mortars the grains of sand impede the free penetration of the needle.

Vicat devised the original apparatus (Fig. 35) for determining the rate of hardening of lime mortars. In the tests as recommended by Vicat, the weighted needle was allowed to fall into the material under test. In the test as now used, the needle is applied carefully to the surface and allowed to sink into the mass under a given weight, Fig. 36 (1). This apparatus has been described under Fig. 36, two pages before. In this test the cap A is replaced by the cap D, and the piston B is replaced by the needle H. The rod L then weighs 300 grams. The hard rubber ring containing the paste of normal consistency is placed under the needle which is gently brought in contact with the surface and allowed to sink into the mass under the load of 300 grams.

For neat pastes the setting is said to have commenced when the polished steel needle weighing 300 grams, does not completely traverse the mass of normal consistency confined in the rubber ring, and the setting is said to be terminated, when the same needle gently applied to the upper surface of the mass does not sink visibly into it.

A thermometer C graduated to 1.5° C. is stuck into the mass and the increase of temperature of mass during setting can be thus observed.

Care should be taken to keep the sides of the needle clean as the collection of cement on the needle retards the penetration of the needle, while cement on the point of the needle reduces the area of needle and tends to increase the penetration.

The test specimens should be kept in moist air during the test. This is best accomplished by placing the specimens on a rack over water contained in a pan covered with a damp cloth kept away from the specimen by a wire screen. The specimens can also be kept in a moist closet.

TENSILE STRENGTH.

The setting of cement is the change from a condition of fluidity to a solid state. When cement has set, the process of hardening is said to commence. The relative degree of hardening at any age is measured by determining its transverse, compressive, adhesive or tensile strength in pounds per square inch.

Of these tests the tensile test is universally used and has met with great favor on account of the convenience with which the test is made and the cheapness of the apparatus required.

The test piece is of one inch section and is shown in Fig. 36 (5). For convenience in molding and removing the briquettes from the molds, the sharp corners should be rounded off with curves of one half inch radius, the briquettes to be of the form shown in Figure 36 (6).

Molds.—The molds should be made of brass or some equally non-corrosive material and can be either of the single or gang-type, the latter is preferable since the convenience and facility for molding several briquettes at one time is greater than in the case of the single mold. The greater quantity of material which can be mixed at a time tends to produce more uniform results.

The convenience in cleaning, compactness and facility with which they can be handled are also arguments in favor of the gang type.

There should be sufficient metal in the sides of the mold so as to prevent spreading of the mold when in use.

The molds should be wiped with an oily cloth before using, this prevents the cement sticking to the mold and damaging the briquette during the removal from the mold.

Mixing.—About one thousand grams of cement makes a very convenient quantity of material to mix at a time and will make about eight or ten briquettes.

The French system of weights and measures because of the relation between the gram and the cubic centimeter is the most convenient to use. The proportions should be stated by weight.

The mixing should be done on some non-absorbing, non-corroding surface, preferably plate glass, although marble or slate would do.

If the mixing be done on a surface of marble or of slate it will be advisable to keep this surface covered with a wet cloth when not in use, or thoroughly wet the surface previous to being used. A surface of this character when not in use, becomes quite dry,

and absorbs some of the water from the first few batches mixed on it; this renders the mortar much dryer and materially affects the results, especially with sand mixtures.

The cement is weighed out and placed on the mixing slab and formed into a crater into which the proper percentage of clean water is added.

The material is turned into the crater with a trowel and when the water is absorbed, the mixing is completed by thoroughly kneading with the hands; the latter process being similar to that used in kneading dough. The duration of the kneading should be about one minute. During this operation the hands should be protected with rubber gloves.

An inexperienced operator should mix for a definite length of time; a one or more minute sand glass is a very convenient guide.

If the person making the test is very inexperienced, it may be necessary to use one half the quantity of material.

When the moisture begins to disappear from the surface and the paste becomes meally and does not stick together, the cement has begun to set and should be thrown away.

Paste which appears to be of the proper consistency at first, becomes quite wet after thorough kneading, while pastes which appear at first quite dry become plastic.

In sand mixtures the mixing should be thorough in order to insure coating each grain of sand with cement. This is a very important feature in sand tests and is often the reason why one person obtains so much higher results than others.

The temperature of the room and of the water used in mixing should be kept as near 70° F. as practical. The air of the room should be kept moist.

A high temperature and dry air in the room in which the tests are made, tends to dry out the test pieces, thereby checking the process of hardening, resulting in low strengths and often in cracking of the test pieces and in some instances disintegration.

Molding.—The mortar having been mixed to the proper consistency is placed at once into the molds with the hands.

The molds are filled at once, the paste is pressed in with the fingers and smoothed off with a trowel on both sides. This should take about two or three minutes for 8 or 10 briquettes. The mortar should be heaped upon each mold and then pressed in by drawing the trowel over the surface of the mold, holding the blade of the trowel at an

angle of about 5° . The mold is turned over and the operation repeated.

The briquettes are marked in the head with steel dies while still soft, or with a large soft lead pencil just before removing from the molds.

An excellent idea of the uniformity of the mixing and molding is afforded by weighing the briquettes upon removing from the molds. The variations in the weight of briquettes should not exceed 3 per cent.

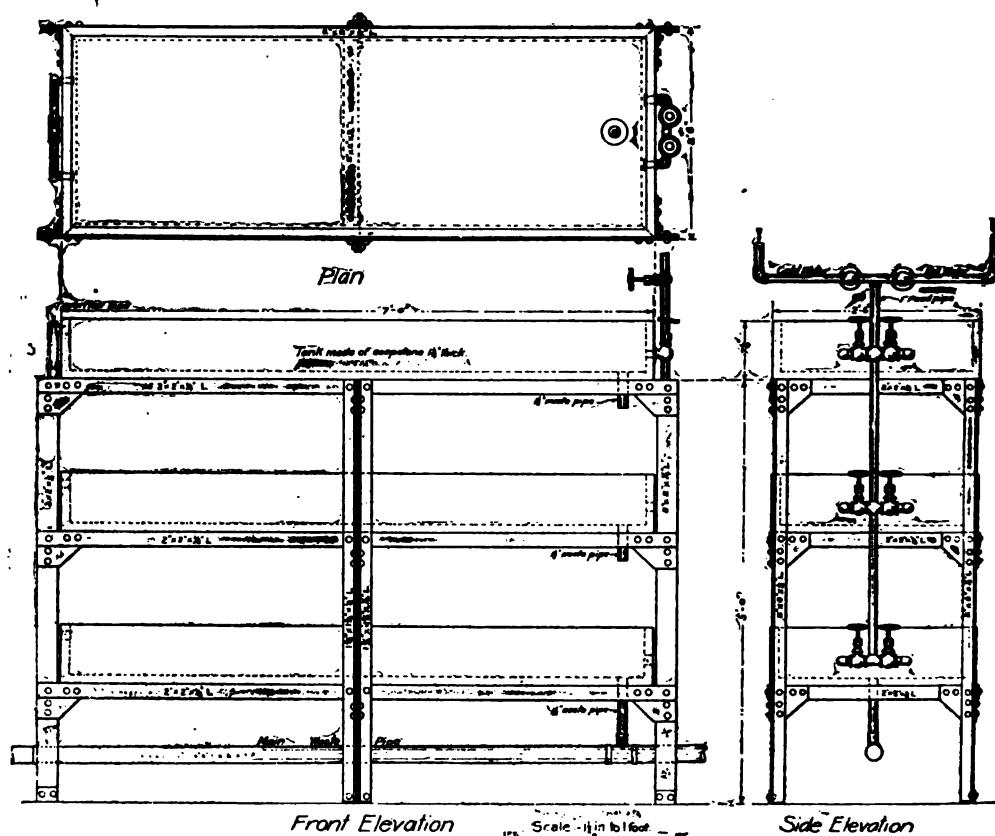


Fig. 37. Box for preservation of briquettes.

Preservation of briquettes.—After the completion of the molding, care should be taken to keep the briquettes in moist air; this prevents them drying out thus checking the process of hardening, and prevents the production of checks and shrinkage cracks.

The most convenient way to preserve the briquettes prior to immersion in water, is by means of a moist box or closet. (Fig. 37.)

This may be of soap-stone or slate, or a metal lined wooden box, covered with felt on the inside; the closet should hold water in the bottom and be provided with shelves on which to place the briquettes or the molds containing the briquettes.

For the twenty-four hour tests the briquettes should be placed in the moist closet immediately after molding and kept there until broken; briquettes to be broken at longer periods should be immersed after 24 hours in moist air, in water maintained as near 70° F. as practical.

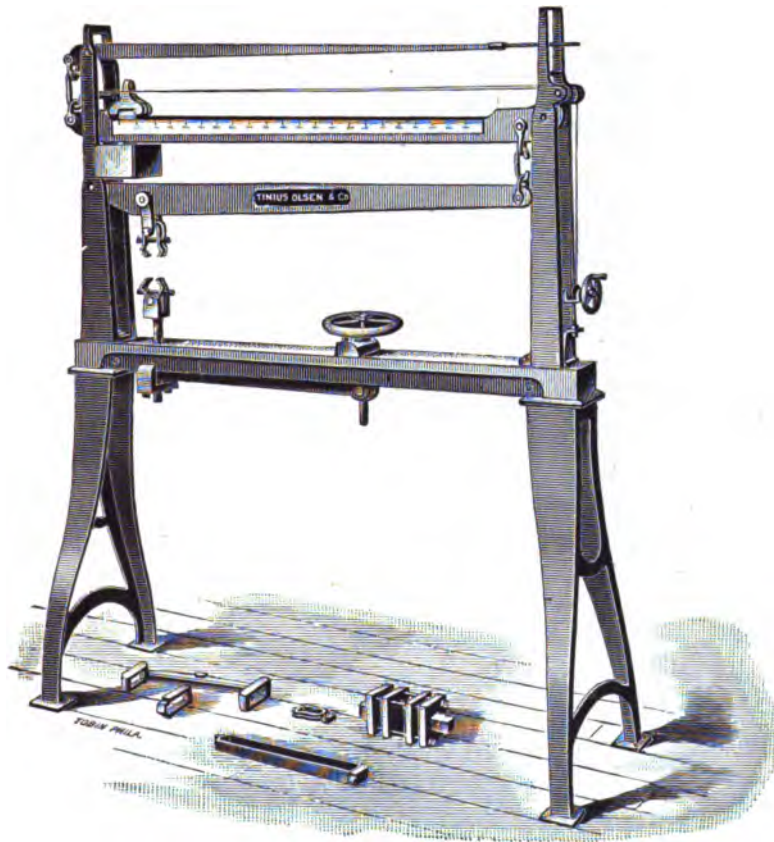


Fig. 38. Olsen testing machine, hand driven.

For preserving the briquettes in water either pans or large tanks are used.

The former should be of the agate ware type, since they do not corrode and are easily cleaned.

A very convenient arrangement for tanks is shown in (Fig. 37). The tanks are in tiers, the supports can be framed of angle iron or

wrought iron pipe. Each tank is provided with a hot and cold water supply pipe and a waste pipe; the inlet being at the bottom and the overflow at the top of the tank. These tanks can be built of soapstone or slate, or they can be enamelled iron sinks.

Where pans are used the water should be renewed once each week. Care should be observed to keep the briquettes covered with water.

When running water is used, care should be observed to maintain the water as near 70° F. as possible.

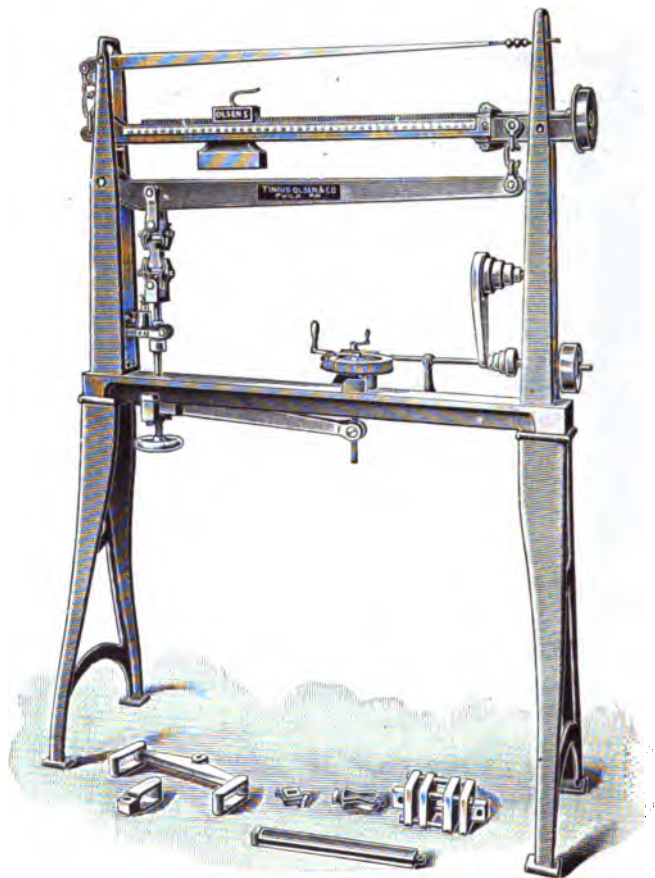


Fig. 39. Olsen testing machine, power driven.

Breaking briquettes.—Briquettes should be broken as soon as they are removed from the water. Care should be exercised in centering the briquettes in the testing machine, as cross strains are liable to result from improper adjustment, producing cross strains which lower the results of the tests. The breaking load should not be ap-

plied too suddenly, as the vibration produced, often snaps the briquettes apart before the full strength is developed.

Figs. 38 and 39 show one form of testing machine.

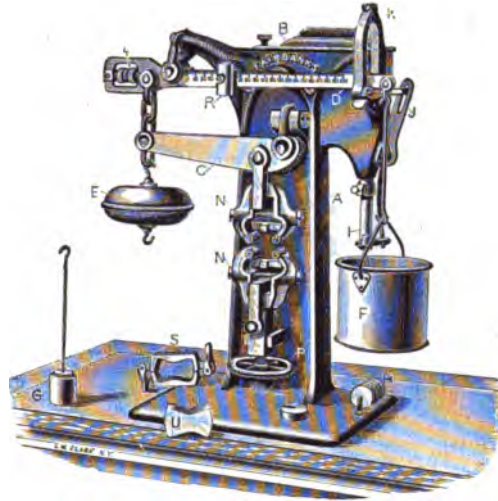


Fig. 40. Fairbanks testing machine.

The clips should be kept clean, and the briquettes free from grains of sand or dirt which would tend to prevent a good bearing.

Care should also be observed in applying the initial load; this is particularly the case with the Fairbanks machine Fig. 40 and constitutes the chief objection to this machine. In long time tests the initial load must be very great, and as there is no way of regulating this load satisfactorily, the variations in the results are often largely due to variations in the amount of the initial load applied. In order to regulate the application of this initial strain, it is the practice in some laboratories to place weights in the shot pan at the commencement of the test, the amount of the weight being dependent upon the age and character (natural or Portland) of the cement under test, the weight increasing with age—it being greater for Portland than for natural cement, and also greater for neat than for sand tests.

It often happens that the last molded and usually the densest briquettes are broken at twenty-four hours or seven days and the first molded or less dense at twenty-eight days or longer. This difference in density may be considerable, in which case the tests may show an apparent falling off in strength. Again, the cement

may begin to set before the last briquettes is molded, and should these briquettes be broken at the long time period, a loss of strength might be again apparent, or even indications of disintegrations appear. All these facts tend to emphasize the necessity of uniformity in mixing and molding in order to secure uniform density in the briquettes, and thus avoid the resultant apparent losses in the tensile strength.



Fig. 41. Riehle testing machine.

CONSTANCY OF VOLUME.

One of the most important tests to which cement is subjected, and one which is the most difficult to make, is that which pertains to the soundness. The methods that have been suggested are legion. This test cannot be used by a novice with safety, and even in the hands of an expert all tests for soundness must be made with extreme care.

The object of the test is to determine whether the cement will maintain a constant volume, and develop no evidence of unsoundness or loss of strength. It is exceedingly important that cement

should not only develop strength but it should also maintain this strength.

Tests of this character can be divided into two classes: (1) normal pat tests and (2) accelerated tests.

The former consists in immersing a pat of neat cement after hard set in water maintained at a temperature as near 70° F. as possible. To successfully meet this requirement it should remain firm and hard and should not check, become distorted or show other evidence of unsoundness.

Months and even years are requisite to develop evidences of unsoundness by this method unless the cement be of very poor quality. The accelerated tests are for this reason in greater favor, because results can be obtained in considerable less time—in a few hours as a matter of fact.

Of the latter class of tests one best adapted to general use is to immerse the pat (after twenty-four hours in moist air), for three hours in an atmosphere of steam coming from boiling water contained in a loosely covered vessel. The pat to satisfactorily pass this test should remain firm and hard and show no signs of checking, cracking, distortion or disintegration. A more reliable test, but one which is more expensive and which requires considerable care in maintaining the water at a fixed temperature, is to immerse the pat (after twenty-four hours in moist air) in water maintained at a constant temperature of 170° F.

One of the difficulties encountered in these tests is in making the pats; these are usually made of neat cement, about three or four inches in diameter, from one-quarter to one-half of an inch thick at the center and tapering to thin edges at the circumference. The pats should be made with the same percentage of water as in the case of the other tests. Simple as the making of these pats may appear to be, it is extremely difficult for inexperienced persons to make them correctly. Pats may be so trowelled as to give initial strains which develop cracks during the test. A good plan is to strike the glass on which the pat is made after molding; this rearranges the mass, drives the moisture through the pat and makes the density of the pat more uniform. Care should be taken that the pats do not dry out—this produces shrinkage cracks, which give a false impression of unsoundness. Most pats leave the glass, and unless this is accompanied by swelling, curvature of the pat, or cracking at the edges, it should not be taken as evidence of unsoundness. In some cases the cement may set before the pat is finished,

and when placed in steam or hot water, the outer edge may lift off. This to the inexperienced is also misleading.

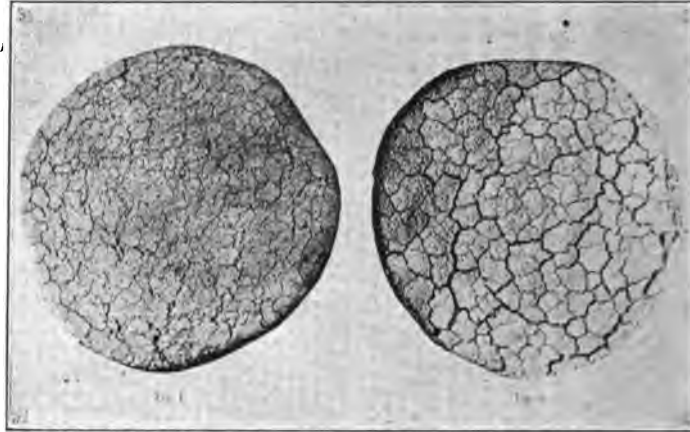


Fig. 42. Result of tests of constancy of volume.

Cements should not be condemned on the results of the accelerated tests alone, nor should a cement be considered sound because it has passed such tests.

The results of such tests are shown in Figs. 42 and 43.



Fig. 43. Result of tests of constancy of volume.

CONCLUSION.

The tests just described constitute those most essential for general purposes in determining the value of cement delivered for use. Tests for determining the compressive, transverse, adhesive or abrasive strength, together with those for determining the effect of frost, action of sea water and the porosity, furnish information having a value for the purposes of research, or where the conditions render such data desirable. Permanent laboratories where work of this kind can be carried on, should be equipped for such tests. Tests of still greater importance, which cannot be used as tests of reception, are those made on the work. These consist in tests of briquettes made from mortar taken from the mixing box or cubes of concrete.

Data obtained from such tests is valuable, inasmuch as it furnishes information concerning the strength of the concrete or mortar taken from the mixing of the mortar or concrete.

There should be some system under which the tests are made, that is, there should be a regular number of briquettes made from each sample, and they should be broken at regular intervals; whenever possible these tests should be extended beyond the regular twenty-eight day period, as it is very desirable to know what the strength is at the end of several years. In addition to the tensile tests, each sample should be submitted to all the tests usually employed. The data obtained from these tests should be carefully recorded in a book kept for the purpose.

Having made the above tests, the interpretations of the results obtained is the next and most serious difficulty which confronts the inspector. It is impossible always to insist on a rigid compliance with the requirements of the specifications, since the failure to meet these requirements may be due to faults in the testing.

It often happens that the person who makes the tests does not use the same amount of energy in each test; this is particularly the case where the number of tests made is large, or the test pieces may dry out or they may be affected by the conditions under which they are preserved.

In cases where the cement fails to meet the requirements, it should be given a re-test before condemning it.

It may be well at this point to call attention to the falling off in tensile strength which occurs at the end of one, two or more months.

Just what causes this action has not as yet been satisfactorily explained.

All cement as it acquires hardness becomes brittle, the length of time required varying from a few months to several years.

In the early stages of the process of hardening, the mass is tough and in a more or less amorphous condition; but as the crystallization proceeds, the mass becomes brittle. It would seem that the loss in tensile strength can be attributed to crystallization.

The modern rotary kiln process is such that we can obtain artificially, in a very short space of time, a result that nature requires centuries to accomplish.

We are required to make tests of a material, which for all practical purposes can be considered a stone; it would seem logical therefore to apply those tests usually applied to tests of stone, i. e., compressive tests.

This would seem to be a proper method for ascertaining the real strength of cement especially for long periods of time.

Tension tests should be used for the purpose of determining the relative value of shipments of cement, and should be confined to tests not extending over 28 days.

When small compression machines, capable of crushing one inch or one and a half inch test pieces, can be built to compete with the present tensile machine, then we will be able to retire the tension tests.

Passing judgment on the quality of a shipment of cement, is one of the most difficult problems that confronts an engineer. You are dealing with a material subject to numerous conditions, any one of which may affect its value as a material of construction. It should be borne in mind that cement is manufactured in one form, tested in another and used in a third. Abnormal behavior in the tests does not necessarily indicate its probable action in actual use.

When we consider the ancient structures which were built with materials of inferior quality (when gauged by our present standards) we are impressed with the hardness and durability of the mortars.

Again it is very rare that we see cases of failure that can be ascribed to the bad quality of the cement. Our facts are not sufficiently established to enable us to state just what qualities or ingredients are requisite for a good cement.

We know, however, as far as our knowledge extends, that the modern rotary kiln product possesses the property of acquiring great strength and hardness in a very short period of time and has thus far been able to resist all normal forces tending to destroy it. What the future will develop only time will tell.

Our system of testing under the best conditions is very imperfect and leaves much to be desired.

Without positive information as to what is required of a good cement, and under an imperfect system of testing it does not seem fair to be too rigid in our requirements.

Testing cement and the interpretation of the results obtained, requires the liberal application of common sense and good judgment, mellowed by practical experience.

No better rule can be observed by the person acquiring his first experience in testing cement than, "When in doubt re-test the cement."

The future alone can prove the correctness of our present theories, and in the meanwhile, in lieu of something better, we must accept our present cements with faith in their high excellence as a building material.

TESTING CEMENT.

381

Constancy of volume.											
Pat in air.				Pat in cold water.				Pat in steam or hot water.			
7 days.	28 days.	6 mos.	1 year.	7 days.	28 days.	6 mos.	1 year.	7 days.	28 days.	6 mos.	1 year.

square inch.						Per cent water.	Remarks.
Compressive.							
1 cement, 5 Standard Sand.							
24 hours.	7 days.	28 days.	Months.	Years.			

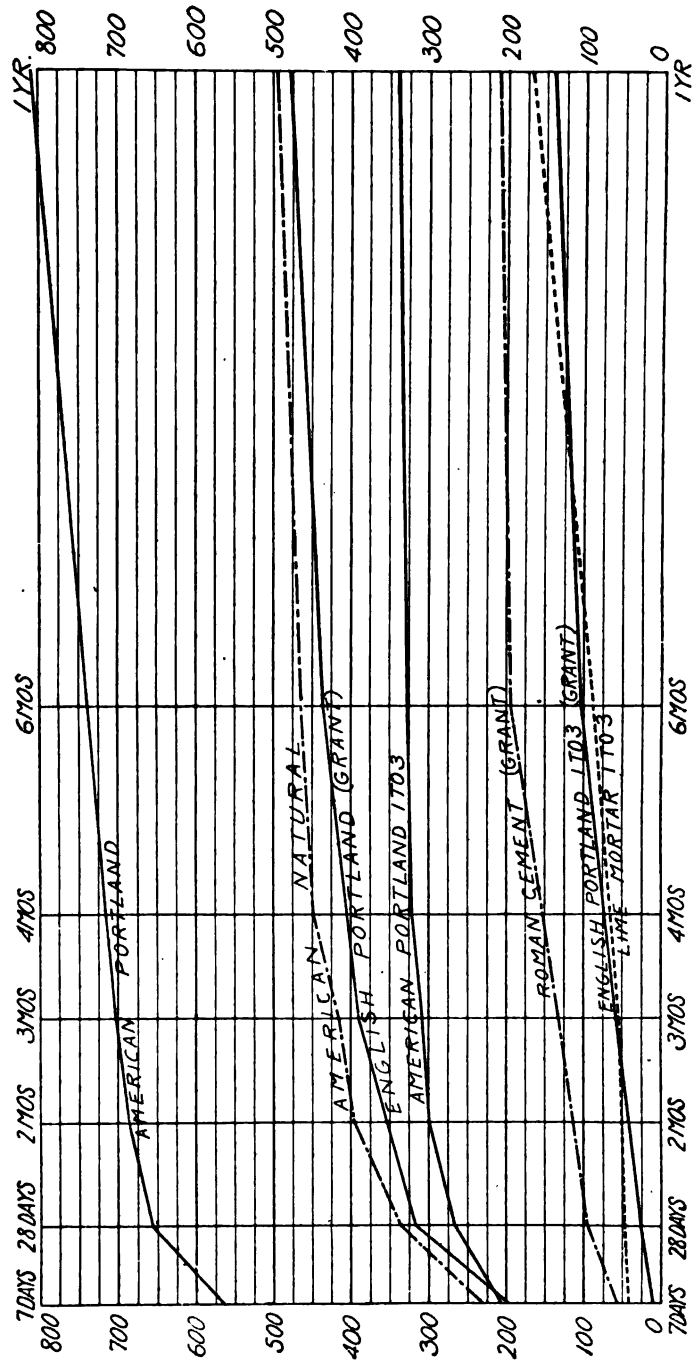


Fig. 44. Diagram illustrating the strength of cement at various epochs, for different intervals after setting.

The above table shows results on samples of Portland cement collected by D. J. Hale and sent to Richard L. Humphrey for testing (not samples which were submitted by interested parties) taken from warehouses where cement was sold every day by retail dealers.

Each sample and each duplicate of a sample were packed separately, first in a paper sack then in a cloth sack, then in a small oblong wooden box just containing the package. Each box then contained but one sample and the sacks could not possibly mix by breaking or sifting.

About 10 or 12 pounds of cement was taken at a time. It was taken as nearly as possible at the center of a sack or barrel, no sack being sampled which by caking showed the effect of moisture, a leaking roof or a situation exposing it to moist draughts of air as between doorways. The duplicate sample was selected in as nearly the same spot as possible to the one in which the first sample was taken. That is, it was selected from the center of the same barrel or sack.

Numbers 3, 4, 7, 8, 10 and 11 were collected at Meecham & Wright's warehouse, 98 Market St., Chicago, Ill. Numbers 1 and 6 Peerless, was sampled from Stevens, Hobbs & Co., Benton Harbor, Mich. Numbers 2 and 5 Bronson, was sampled from Jno. Wallace & Co., St. Joseph, Mich.

The following are the numbers and names of the samples taken :

- No. 1. Peerless.
- No. 2. Bronson.
- No. 3. Atlas limestone cement, made at Coplay, Pa.
- No. 4. Atlas—Duplicate of No. 3.
- No. 5. Bronson—Duplicate of No. 2.
- No. 6. Peerless—Duplicate of No. 1.
- No. 7. Dykerhoff.
- No. 8. Alsen's Portland Cement, from Jtzehoe, Germany.
- No. 9. Wolverine, taken at Thomas Moulding's warehouse, 40th and Wentworth Sts., Chicago, Ill.
- No. 10. Dykerhoff—Duplicate of No. 7.
- No. 11. Alsen—Duplicate of No. 8.
- No. 12. Wolverine—Duplicate of No. 9.

The samples were submitted to Mr. Humphrey with the number only and not the name of the manufacturer or statement of which were duplicates.

NOTES BY D. J. HALE.

Upon consideration of these results the following comments appear to be suggested.

The specific gravity checks the closest of all the tests and would serve to identify the duplicates as such. The specific gravity of well made cements does not vary greatly, and in the case of these cements the total variation is only 14 per cent. The duplicates, however, vary from each other very slightly indeed, three sets agreeing and three varying, one duplicate from the other, one per cent (Nos. 1 and 6, 3 and 4, 9 and 12).

Fineness seems to have agreed best with the 50 mesh sieve. In this test three out of six pairs gave identical results. This was not paralleled in the tests on the 100 and 200 mesh sieves, the divergence between brands in several instances not being as great as that between duplicates.

Duplicates only can be compared as to setting, since different percentages of water were used, duplicates, however, receiving the same. It will be noticed that the greatest divergence in initial set between duplicates 2 and 5 occurred when the air temperature varied. However, in 3 and 4 there was the same difference in air temperature with a difference of only seven minutes in the initial set. It can be seen that even with the careful effort here made to keep temperatures as nearly as possible equable the time of setting is very difficult to keep even, and as a source of comparison between respective brands would scarcely be reliable, as the divergence between samples is in many cases not as great as that between duplicates.

The tensile strength appears from a comparative point of view the most unsatisfactory of the tests. In the 96 tests made there were but two instances in which duplicates gave the same number of pounds breaking test, 3 in which they varied 2 pounds from each other, 3 in which they varied 3 pounds from each other. The greatest variation between duplicates was 159 pounds. On the other hand so often do the duplicates differ more from each other than from other brands that it does not seem as if this test could show which was the sounder of two brands. For example take 1 and 6, 24 hours neat. The difference is 80 pounds; between 6 and 5 which are not duplicates but rival brands, 57 pounds; between 6 and 2, rival brands, 23 pounds.

There can be no doubt that this set of tests was made as carefully as they could be made by our present methods of testing. In a general way some test higher than others but in such an uncertain manner that excepting for the specific gravity test it would scarcely be possible to pick out by means of the record here shown, those samples which were duplicates from those which were different brands. It can scarcely be fair to allow one set of experiments no matter how carefully carried out to settle the question of whether or not our present methods are an actual test or not of the quality of our cements. This series seems to accentuate the emphatic declarations of Mr. Humphrey and many who are called upon to investigate the merits of different cements by present methods, that these methods are of small value as an actual test. They cannot, however, be totally condemned until a better system is devised. It is also not to be forgotten that the water and steam test showed all to be first-class cements. While this test does not serve to distinguish between good cements, it should certainly not be discarded because it is valuable in detecting a worthless brand.

INDEX TO PART III.

A.		Analyses.—Con.	
Absorption, rates of.....	209	of cement.....	360
Acids, chlorine, etc.....	37	of clay 137, 171, 222, 241, 288,	
Acid, sulphuric.....	37, 50, 345, 361	291, 296, 322, 323, 327, 329,	
phosphoric.....	37, 50	330, 332, 334, 336, 337, 339,	
See names of bases and also		346, 347, 352	
ANALYSES.		Bronson.....	239
Ackers Point, 17, 110, 111, 113, 114,		Millbury.....	229
120, 129		of Cloverdale samples.....	20
Addison Lake.....	228	of Coldwater marl.....	76
Adhesive strength of mortars, ap-		of Fremont Lake marl.....	136
paratus for determining.....	355	of gas.....	203
Adulterants for paints.....	4	Partial, of samples collected	
Agricultural Bulletin No. 99....	337	by D. J. Halé, and analyzed	
Alabaster	334	by A. N. Clark.....	21
Alamo, Kalamazoo county.....	310	of kiln brick	176
Albion.....	314	of limestone.....	339
Alcona County.....	334	of Littlefield Lake marl.....	76
Algae, fresh water, lime precipita-		of marl 8, 32, 48, 75, 76, 103,	
ting agents.....	90, 92, 221	136, 218, 226, 236, 240, 279,	
See also CHARA.		283, 287, 291, 292, 295, 298,	
Alkalies, effect of, on solubility....	210	315, 316, 318, 319, 320, 321,	
Alpena County.....	33, 179, 388, 339	324, 337, 338, 339, 342, 344, 353	
Alpena Portland Cement Company		methods of.....	218
180, 224, 225, 338		Millbury clay	229
Alsen's Portland Cement, test.....	382, 384	Pittsburg coal.....	231
Alma Sugar Company.....	73	Portage Lake marl.....	157
American engine practice	168	Quantitative	72
American Portland.....	383	of raw material used by	
American Society of Civil Eng'rs..	299	Wolverine Portland Ce-	
Amnicola limosa.....	98	ment Co.....	247
Amnicola lustrica.....	98	of waters.....	46, 99
Analyses.....	5, 46, 121	of Goose Lake.....	234
Analyses by Gustav Bischof.....	56	White Pigeon.....	103
by C. H. Hess.....	233	Antrim County.....	16, 338
by Frank S. Kedzie.....	153	Apparatus to determine depth and	
by L. S. Leltz.....	73	outline of marl beds.....	108
by Delos Fall.....	153	for cement tests.....	356
See FALL.		Appearance of marl.....	31
of Bronson clays.	239	See also MARL.	
marls.	105	Aral, bed of marl near	338
of Cedar Lake marl.....	75, 76	Arbela Twp., Tuscola Co.....	321

- Arenac Co.**..... 326
Arendale Hill...... 328
Armstrong, G. M. S...... 171
Artesian stratum...... 323
Ash..... 312
Aspedin, J...... 159
Athens...... 301, 352
Atlas Co. cement...... 175, 179, 382
Au Gres River...... 334
Au Sable...... 336, 337
- B.**
- Balker (or Backus) Lake** 17, 19, 107,
 119, 122, 123
Bad Axe...... 321
Bair Lake..... 313
Bakie Loch, Forfarshire...... 78
Baldwin..... 333
Ball principle of grinding...... 181
Barlow Lake...... 318
Barus..... 85
Barry..... 310, 317
Barrytown...... 326
Bass Lake...... 322, 333
Bay City...... 167
Bay County...... 328
Bayous, marl in...... 16
Bear Creek...... 331
Bear Lake...... 137
Beebe, C. E...... 282
Beechwood Point...... 115
Beers, Henry...... 151
Bellaire Portland Cement Co...... 306
Bellevue..... 317
Benham, F. G...... 293
Benzie County...... 137, 327, 338
Berrien County...... 314
Betsey River...... 328
Bevin Lake...... 276, 277
Bicarbonated salt...... 59
Bicarbonates...... 202, 211
 See also CALCIUM, MAGNE-
 SIUM and ANALYSES.
- "Big Marsh"**..... 333
Big White Fish Lake...... 20, 131
Bineau...... 209
Bischof, Gustav...... 56, 209
Black Lake...... 340
Blind Island...... 290
Bog iron...... 124
Bog iron ore...... 49
Bog lime...... 307, 313, 342
 See also MARL.
 Analyses of..... 226
 Deposit of, near Fish Lake.. 317
 General description of..... 307
 near Eaton County..... 317
 near Kelly's Corners..... 315
 near Lacey's lake..... 317
 lakes..... 325
 near Leslie..... 316
 near Oak Grove..... 316
 origin of..... 41, 199
Bones..... 234, 249
Boussingault and Levy...... 209
Boutron and Boudet...... 209
Brickyard..... 147, 150
Britten, Deerfield township...... 312
Branch County...... 313
Brigden, Mr. W. W...... 349, 350
Briquettes of cement...... 161, 370, 372
Bristol, H. C...... 334
Bristol Lake...... 313
Bronson 1, 103, 104, 163, 167, 171,
 173, 182, 228, 384
Bronson Lake...... 333
Bronson clays, Analyses of...... 239
Brosch estate...... 332
Brotherton, W. A...... 316
Brown, F. W...... 176, 177
Buell...... 320
Buildings..... 188
Bulrushes...... 283
Bunsen..... 209
Burning...... 174, 179
 cost of..... 178
Burning Dept...... 178
Bush Lakes...... 277
- C.**
- Calcareous clays.**..... 5
Calcareous tufa...... 335
Calcium..... 205
Calcium bicarbonate...... 206, 207
Calcium carbonate...... 34, 47, 50, 56,
 313, 318
 See also MARL, BOG LIME
 and ANALYSES.
 Solution of..... 200, 210
 Effect of, on marl..... 296

- Calcium carbonate.**—Con.
 Compared in parts per million, Horseshoe, Long, Guernsey, Pine and Mud Lakes..... 131
 Precipitation of..... 55
Calcium hydrate..... 172
Calcium oxide..... 192
Calcium succinate..... 87, 88, 89
Calhoun County..... 311, 314
Calhoun Lake..... 150
Campbell, E. D...... 158, 291, 348, 349, 350
Canada, extension of marl in..... 6
Canten..... 307
Carbonates..... 342
 See also ANALYSES.
Carbonate of iron..... 211
Carbonates, magnesium..... 50
 Solubility of..... 45, 200
Carbon dioxide, dissolved..... 86, 362
Caro..... 211
Carp Lake..... 328, 330, 331, 332, 333
Carpenter, Prof. R. C...... 293
Case, James..... 331
Cascade Township..... 99, 314
Cass County..... 33, 313, 321
Castalia, Ohio..... 78
Cedar Lake, in Montcalm County,
 18, 33, 80, 91, 99, 100, 322, 323, 324, 335
Cedar Run..... 328
Cedar Springs..... 99
Cederberg, A. H...... 190, 298
Cement..... 160, 224
 Adulterated with coarse materials..... 181
 Amount of material for..... 294
 Chemical analysis of..... 360
 Cooling of..... 179
 Constitution of..... 172
 Curing of..... 180
 grinding..... 180
 industry..... 189
 Making of..... 171
 manufacture, Adaptibility of marl to..... 2
 Mill tests of..... 358
 "Silica"..... 181
 specifications..... 186, 188
 Tensile strength of..... 297, 300
 testing, Humphrey's report on 188
 Tests of..... 280, 357
Cement and Engineering News,
 224, 233
Cement City..... 33
Cement factories, Burning of..... 189
Central Lake..... 16, 20, 46, 59, 63, 142, 145, 146, 148, 150, 338
Central Lake, Antrim County..... 143
Chalk..... 6, 160
Chambers, C. A...... 312
Chapman Lake..... 252, 253
Chamberlain's well..... 118
Chara, agent in marl production, 73, 78
 deposits..... 306
 foetida, analyzed by Gustav Bischof..... 56
 fragilis..... 89
 fragments, Analysis..... 4, 86, 220
 hispidia..... 78
 in lakes of Denmark..... 78
 lyelli..... 78
 material..... 317
 Method of concentration by..... 87
 plants, Limit of depth..... 86
 Source of thick crusts on..... 79
 (Stonewort), 56, 57, 58, 60, 70, 71, 73, 74, 77, 78, 82, 83, 88, 89, 95, 223, 287, 335
Cheboygan County..... 340
Chemical analyses..... 282
 See ANALYSES.
Chemical effect of marl on fertilizers 4
 theory of precipitation of marl 42, 44, 58, 64
Chester..... 311
Chlorophyl..... 57, 112, 122
Clam Lakes..... 338
Clapp, Theodore E...... 103
Clare..... 151, 168, 294
Clare County..... 293, 327
Clare Portland Cement Company..... 293
Clarke, J. M...... 90
Clark, A. N., Analyses..... 20, 21, 319
Clark's Lake..... 309
Clarkston..... 316
Clays, Michigan..... 345
Clay..... 105, 147, 149, 167, 170, 192, 296, 299, 322, 324, 327, 329, 331, 333, 336, 338, 339, 346
 Analyses of..... 137, 171, 222, 241, 288, 291, 296, 322, 323, 327, 329, 330, 332, 334, 336, 337, 339, 346, 347, 352

- Clay—Con.**
 on Clout's farm..... 20
 Calcareous..... 5
 for cement..... 331
 Hubbell collection of fifty-two
 328, 333
 Effect of on marl..... 230
 land..... 286
 Marly..... 8
Clay shale..... 227
Clayton Lakes..... 301, 303, 304, 305
Clinker grinding..... 177, 179, 183, 184
Clinton County..... 320
Clippert & Spalding's brick yard.. 147
Cloverdale Lakes.. 13, 14, 17, 18, 25,
 49, 52, 107, 114, 115, 117, 118
Coal..... 175, 185
 dust..... 175
 series..... 334
Cobb Lake..... 318
Cohn..... 65
Coldwater shale..... 149
Coldwater 77, 103, 104, 105, 106,
 175, 228, 313
Cole, John..... 136, 137
Collins, Mr. F. S., Walden, Mass... 90
Colon..... 55
Columbus Township..... 309
Composition of raw material..... 40
 Commercial importance of... 30
 See ANALYSES.
Consistency..... 364
Covis Township..... 314
Cooper Township..... 310
Cooper, W. F...... 317
Copemish..... 328
Corey..... 332
Cerinne..... 20, 46, 140, 340
Cerunna..... 293
Cossa..... 209, 215
Cest, Estimates of..... 178, 186
 of construction of cement
 plant..... 194, 196
 of manufacture..... 197
 of burning..... 178
Courtis, W. M., Analyses by... 287,
 318, 337, 339
Craue, use of..... 166
Crape Lake..... 252, 254
Crow's Farm..... 147
Cruse on solubility..... 209
Crystal Lake..... 138
Crystals..... 219
"Curling"..... 185

D.
Davis, C. A...... 43, 64, 65, 97, 100,
 199, 217, 273, 292, 322
Dayton, Simon..... 118
Dean's clay, Sherman..... 329, 330
Dean, J. G...... 170, 200, 233, 332
Detroit Journal..... 224, 237
Detroit Portland Cement Company 320
Devonian black shale..... 149
Devore Lake..... 334
Diatoms..... 36, 73, 91
Dickson Lake..... 276
Digging..... 165
Dipper dredge..... 166
Dolbee, Chester..... 317
Dolomite, solubility..... 210
 in clay..... 222, 327, 336
Deeley, J., farm N. E. of Albion... 315
Deolittle, R. E...... 251, 281
Douglass, C. C...... 312
Douglass Houghton Survey..... 306
Dowagiac..... 313
Draining..... 166, 344
Dredging..... 166
Dome kiln..... 161
Drummond Island..... 341
Duck Lake..... 46, 142, 228, 328

E.
East Jordan..... 46, 148, 150
East Lake..... 328
East Tawas..... 334
Eaton County..... 310, 314, 317
Eddystone lighthouse..... 159
Edwards Lake..... 251, 252, 253
Egyptian Portland Cement Co.... 316
Electrical installation..... 195
Elk..... 248
Elk horns..... 234
**Elk Rapids Portland Cement Com-
 pany Plant**..... 189, 244
Elwell, Pierce..... 316
Emmet County..... 340
Empire Cement Company..... 296
Engel and Ville..... 210
England, cement materials of.... 160
Escanaba..... 15, 62, 138

- Evaporation..... 220
 Exeter..... 312
 Expense of raw grinding at Lupton 174
- F.
- Falji, Henry..... 180
 Fairbanks Machine..... 373
 Fall, Delos, Analyses by 136, 154,
 301, 302, 304, 305, 306, 328, 336,
 342, 352, 353
 paper by..... 343
 Farr, A. W..... 157, 333
 Farr's Liquid Marl Sampler..... 11
 Farwell..... 294
 Farwell's Lake..... 310
 Farwell Portland Cement Co..... 292
 Ferric oxide and alumina..... 35
 Fertilizer, (marl)..... 3, 4
 Fineness of cement..... 363
 Fineness of grinding, effect of on
 cement..... 181, 349
 Five Lakes..... 293
 Fish Lake..... 317, 353
 Flint pebbles for grinding..... 234
 Ford, J. B..... 248
 Forfarshire..... 77
 Frankfurt..... 138, 141
 Freight rates..... 193
 Fremont Lake..... 99, 135, 240, 326
 Fremont Lake marl, Analysis of
 136, 326
 Fremont flowing well..... 46
 Fresenius..... 209
 Fuel..... 174
- G.
- Gamble Lake..... 334
 Gases in rain water..... 209
 Geikie, A..... 78
 Geiger Lake..... 323, 324
 Genesee County..... 275, 320, 321
 George Lake..... 252
 German Portland Cement Co..... 291
 Gladwin County..... 326
 Goose Lake..... 33, 100, 233, 352
 Gordon, C. H..... 147
 Grabau, A. W..... 225, 227
 Grand Rapids..... 33, 206
 Grand Traverse County..... 338
 Grand Traverse Region..... 141, 327
 Grant, John..... 357
- Grass Lake..... 33, 228, 286, 310, 338
 quantity of marl in..... 283
 Grattan Township..... 319
 Gratiot County..... 100, 322
 Grayling..... 33, 337
 Great Marl Lake..... 240
 Great Northern P. C. Company... 327
 Greenbush..... 335
 Greening, Chas. E..... 243
 Greenland chert pebbles..... 181
 Greensand Marls..... 5
 Green Oak Township..... 316
 Gregory, W. M..... 227
 Gridley..... 310
 Griffin mill..... 180, 181
 Grinding, Fineness of..... 181, 349
 Guernsey Lake 19, 46, 52, 53, 107,
 124, 130
 Gypsum..... 345
- H.
- Hale, D. J. 20, 21, 91, 199, 292, 313,
 325, 384
 record of field work by..... 102
 Hanover..... 228, 310
 Hard water lakes... 58
 Hardness of Water..... 118
 Harrietta..... 138, 330
 Harrisville..... 334, 335
 Harwood Lake..... 313
 Hassan, Tagge and Dean..... 158
 Hastings Lake..... 228
 Hauer, K. von..... 210
 Heath, Geo. L..... 342
 Heat necessary to produce clinker,
 Amount of..... 176
 Hecla Portland Cement and Coal
 Company 40, 166, 179, 185, 250,
 251, 326, 334
 Helm, H. and W..... 322
 Helmer..... 313
 Herring Lakes..... 138, 297
 Hess Lake..... 240
 Hess, W. H..... 233, 281
 Hickory Creek..... 154
 Higgins Lake..... 91
 Hillsdale..... 308, 313
 Hodge, Dr..... 235
 Hoke, B..... 332
 Holden..... 320
 Holly..... 316

- Homestead P. O.**..... 331
Hood, A. P...... 181
Hope Township..... 119
 See CLOVERDALE.
Horicon..... 328
Houghton..... 341
Horseshoe Lake 19, 46, 49, 52, 53,
 55, 56, 58, 119, 122, 123, 124,
 126, 130
 soundings of..... 121
Howard City..... 325
Howell..... 99
Hubbard, Bela..... 309
Hubbell, J. J...... 327, 338
Humphrey, R. L. 188, 240, 354, 382, 384
Hunt, T. S...... 210
Hunt, Robt. G. & Co. 13, 158, 274, 280
Huron..... 231
Huron Valley..... 308
- I.
- Identification**..... 9, 308
Ignition, Loes on..... 192
Illinois, Extension of marl in..... 6
Indiana Lakes, Extension of marl
 in..... 6, 99, 167
Engineers, Proceedings..... 158
Ingham County..... 316
Interlechen..... 142
Intermediate Lake..... 142, 338
 See CENTRAL LAKE.
Ionia County..... 311
Iosco County..... 334
Iron, bog..... 124
Iron, effect of on marl..... 231
Iron oxide, deposit of..... 50
Isabella County..... 326
- J.
- Jackson County**..... 309, 315
Jackson..... 310
Johnson Lake..... 228
Jonesville..... 106
Jordan Lake..... 319
- K.
- Kalamo**..... 310
Kalamazoo..... 1, 106, 161, 162, 310, 311
Kalamazoo County..... 310, 314
 marl, analyses..... 353
Kalamazoo River..... 310, 312
Kalkaska County..... 338
- Keating, Mr.**..... 325
Kedzie, Frank S., Analyses..... 154,
 288, 292, 321, 323, 326, 334
Kent County..... 311, 318
Kerner..... 78
Kimball..... 240
Kiln brick, Analyses of..... 176
Kiln, continuous..... 161
 Dietsch and Schofer..... 196
Kiln process of cement manufac-
 ture..... 162
Kiln, Rotary..... 162
Kiln, set..... 196
Kippenberger..... 215
Kirk, Ludington..... 335
Kleinheksel, John H...... 151
Kynion Lake..... 301, 303, 304, 305, 314
Kupffer, A...... 210
Kuster's work..... 215
- L.
- Laber Commission**..... 224
Lacey's Lake..... 317
Lagendorfer..... 182
Lake Bluff..... 332
Lake Cochituate..... 51
Lake County..... 327
Lakelands..... 288, 289
Lake Leelanaw..... 332
Lake Spring and water..... 51
Lane, A. C...... 2, 91, 97, 99, 100, 199,
 347, 349
Lansing..... 218
Lapeer County..... 321
Lathbury, B. B...... 158, 191
Lathbury and Spackman..... 2, 158,
 171, 174, 179, 186, 198, 199, 224,
 251, 298, 299
LeChatelier, tests by..... 172, 362
Leelanau County..... 327, 328
Lehr Lake..... 301, 303, 304, 305
Leland..... 333
Lelitz, L. G...... 73
Lenawee County..... 233, 312, 327, 338
Leoni..... 310
Leslie Township, marl..... 307, 316
Liberty..... 309
Lime kilns..... 3, 140
Lime..... 345
Lime, see CALCIUM and MARL.
 Effect of, on clinker..... 230
Lime Lake..... 20, 50, 133, 134, 233

Limestone, Analyses	339
Limestone flour	222
Limnea humilis	98
Lincoln	334
Little Lake	15, 139
Littlefield Lake ..77, 85, 92, 95, 273,	
292, 293	
Little Marl Lake	240
Little Traverse Bay	141
Little Whitefish Lake	131, 132
Livingston County	316
London	312
Long Lake ..17, 18, 25, 46, 52, 58, 62,	
106, 107, 110, 117, 118, 119, 120,	
123, 124, 126	
Caustic marl of.....	115
Soundings of.....	124
Loranger, U. R.	251
Lower Black River	340
Ludington's Spring	334
Ludwig	118
Lupton	185, 189, 298, 299
Expense of raw grinding at..	174
Lupton Portland Cement Company	297
Lyell, Sir Charles	77

M.

Mackinaw City	141
Macomb County	315
Magnesia.....128, 169, 170, 192, 223,	
342, 345, 349	
See also ANALYSES.	
Magnesia or alumina brick	175
Magnesium carbonate	35, 210
bicarbonate.....	213
oxide.....	192
Maine	97
Manistee and Northeastern rail-	
road.....	338
Manistee	154, 327, 328, 331
Manistee Junction	46, 150
Manistee River	331
Manistique	140, 341
Manufacture of Portland Cement	
from marl.....	158
Marble	6
Marengo	311
Marshall	311
Materials for cement	160
Marl, Acreage of	302

Marl—Con.

Adaptability of, for cement	
manufacture.....	2
analyses..8, 32, 48, 75, 76, 103,	
136, 153, 157, 218, 236, 240,	
279, 283, 287, 291, 292, 295,	
298, 315, 318, 319, 320, 321,	
324, 337, 338, 339, 342, 344, 353	
Appearance of.....	31
Average of volume to barrel.	168
in bayous.....	16
beds, without chara.....	81
bed, sealed.....	17
bed, increase and decrease in	
depth of.....	17
Caustic.....	124
Chemical precipitation of ...	58
claims.....	312
and clay in Michigan.....	343
and clay in properties, De-	
velopment of, for Mfg. of	
Portland cement.....	191
Suitable time for investi-	
gation of.....	191
Tests to be made of.....	192
Necessary composition of....	169
and origin of.....	32
Contamination of.....	7
covered with water.....	13
deposits, Relation of to direc-	
tion of prevailing strong	
winds... ..	96
Requisites for.....	169
Deposition of.....22, 63, 66	
upon aquatic plants.....	69
Depth of.....	169
Distribution of.....5, 6, 9	
in a single bed, 16	
as fertilizer.....	309
formation.	54, 62
found in hard water lakes... 14	
Gradation in quality of..... 18	
Grain of.....	170
Granular structure of.....	74
Impure.....	48
Indication of, by circum-	
stances of occurrence.....	47
Interpretation of.....	34
Lake.....275, 276, 292, 322	
lakes, Level of.....	15
Location of, according to	
counties.....	312

- Marl**—Con.
 Location of.....13, 15
 Location of, Conditions governing.....22
 Location and size of bed.....38
 manufacture, magnitude of cost of.....2
 Materials, overlying.....29
 underlying.....28
 Natural history of, Contribution to.....65
 Organic matter in.....21
 See also SUCCINIC ACID.
 Origin of.....2, 323
 and peat.....82
 precipitate.....58
 Precipitation of.....59
 Precipitated in deep water..52
 Pure.....61, 83
 Quality of.....61, 193
 Quality and formation of, Change in.....62
 Quantity of.....278, 283
 Settling of.....84
 shells.....97
 stages or steps or growth of..17
 Surroundings of.....23
 Tufaceous.....311
 Ultimate sources of.....66
 Uses of.....3
 Underlying cedar swamp....93
 Wet.....177
Marshgrowth, Lining of.....27
Maskego Lake.....312
Mason County.....327
Mastodon.....313
Material for cement, Amount of..294
McLouth, C. D......137
McMillan.....90
Medway.....160
Merkell's.....210, 215
"Merl" or Marl Lake.....83
Meecosta County.....326
Michigan.....65
Michigan Alkali Co., Wyandotte
 (J. B. Ford).....248
 Description of plant.....248
Michigan clays.....171
 Extension of marl in.....6
Michigan Miner.....227
Michigan Portland Cement Co. 33, 315
Midland County.....326
Mikado.....335
Milton.....311
Milwaukee.....182
Millbury.....170, 229, 336, 337
Mineral Lake.....276
Mill tests of cement.....358
Mills Lake.....252, 255
Millstone.....180
Missaukee County.....333
Mixing cement.....368
Mixing materials, Methods of....161
Mixing and raw grinding.....173
Molds, cement.....368, 369
Mollusca.....68, 101
Monroe.....307
Monroe Center.....331
Monroe County.....312
Montcalm County.....322
Montmerency.....338
Mortars, Adhesive qualities of....355
Moscow.....228
Mosher's Lake.....228
Mosely.....78
Motive power.....184
Mound Springs.....20, 147
Muck, Marly.....8
Muck or peat.....343
 See PEAT.
Mud or Round Lake....14, 46, 117, 129
Mud Lake, Hope Township..52, 53,
 62, 100, 116, 118
 Oakland County.....275, 276, 280
 Ionia County.....320
 Genesee County.....320, 321
Muir, Ionia County.....320
Mullett Lake.....340
Munising.....139
Murray, G......90
Muskegon County.....137, 325

N.
Napoleon.....309
Naubinway marl.....33, 340
Nellist, J. F......318
Nelson, W. S......324
Nettle Lake.....313
Newaygo County.....325
Newaygo Portland Cement Co.,
 (Gibraltar).....189, 240, 241
Newberry.....172, 176

- Newell's steam mill..... 312
 New England..... 65
 New Jersey marl... ..3, 5
 New York..... 78
 Niles98, 107
 Northbranch Township..... 321
 Northcote..... 210
 North Island..... 144, 145, 146
 North and South Carolina marls.. 5
- O.
- Oak Grove, Bog lime near..... 316
 Oakland County.....275, 308, 316
 Oceana County..... 325
 Ogemaw County..... 334
 Ohio.....167, 337
 Engineers' proceedings..... 158
 Olsen testing machine.....371, 372
 Olsen Lake 325
 Omega Portland Cement Company
 168, 173, 179, 227, 232, 308, 313
 Onkama Lake.....28, 154, 328
 Organic matter27, 37, 345
- See also ANALYSES.
- Origin of marl..... 2
 Orion 321
 Osborn Company.....158, 232
 Osceola County 327
 Osceola County 337
 Ottawa.....312, 318
 Otsego County 338
 Overburning..... 179
 Owosso..... 200
 Oxides of iron and alumina..... 192
- P.
- Paints, Adulterants for..... 4
 Parmelee, H. P..... 42
 Pasley 355
 Pat tests..... 375
 Paw Paw River..... 154
 Peat..93, 281, 303, 314, 317, 320, 322,
 325, 343
 Peerless Portland Cement Co..237,
 310, 384
 Penhallow..... 90
 Peninsular Portland Cement Co.
 233, 313
 Pentwater..... 325
- Per cent of water used in mixing
 cement.....182, 349, 366
 Perry, C. W., of Clare..... 293
 Petobago Lake..... 245
 Petroleum 175
 Pettenkoper 209
 Phosphoric acid.....37, 50
 Pickerel Lake, Newaygo County,
 99, 240
 Pierson 326
 Pierson Lakes..... 131
 Pine Creek..... 46
 Pine Lake...19, 46, 53, 81, 107, 126,
 131, 148
 Deep waters of..... 53
 Soundings at..... 127
 Placidium..... 98
 Placidium contortum..... 97
 Pittsfield, Mass..... 97
 Planorbis parvus..... 97
 Planorbis bicarinatus..... 98
 Plant life, Decayed 27
 Plants, Fixed.....59, 60
 Platte Lake, Little..... 333
 Platte River.137, 329
 Platte Township..... 331
 Plummer Lake.....252, 254
 Plymouth Township 307
 Portage Lake, Onkama...17, 63,
 154, 155, 333
 "Portland," Origin of name..... 158
 Portland cement, Manufacture of. 158
 Power, Cost of..... 185
 Prairieville..... 317
 Precipitate of crystals...217, 218, 220
 Presque Isle County 339
 Price Lake..... 52
 Proceedings, Ohio Society of Sur-
 veyors and Civil Engineers, 158
 Proceedings, Indiana Eng. Soc.... 158
 Prophet, John..... 340
 Prospecting, Methods of 29
 Prospecting tools.....9, 139
 Pulaski 310
 Pupids..... 98
 Pyramid Portland Cement Com-
 pany.....291, 352
- Q.
- Quicklime.....3, 308
 Quincy103, 104, 106, 175, 228

- R.
- Raffee Lake.....273, 275, 276
Ransome rotary kiln.....1, 174, 175
Raw material, Admixture of.....171
Record book, Form of.....380
Reading.....313
Reed City.....151
Reed, George.....324
Rice Lake.....21, 29, 59, 151, 152, 156
Rice reeds.....142
Riley and Sizanne, chara lime-stones.....78
Rim roller.....180
Riverdale.....325
Rives.....310
Robinson, H.....293
Rock cement.....334
Rock Islet.....122
Rock Lake.....322, 323
Rocky Island.....113
Roman cement.....354
Roscommon County.....333
Rosevear, W. B.....341
Ross, Kalamazoo.....310
Rotary kiln.....1, 179
Rotary process.....163
Round Lake.....46, 107, 110, 290
Runciman, J. H., Mill lake.....315
Runyan Lake.....274, 275, 283
Russell's farm.....331
Russell, I. C.....158, 180, 288, 291, 349
- S.
- Sage Lake.....334
Saginaw Bay.....90
Saginaw County.....322
Sagittaria.....284
St. Clair County.....321
St. Ignace.....141
St. Joseph.....307, 313
St. Joseph's River.....154
Saline Springs.....307
Salts Bicarbonated.....59, 60
- See BICARBONATES.
- Salt (sodic chloride), effect on sol.. 213
Salt wells.....177
Sampling cement.....359
Sand.....28, 161, 170
Sand lake.....228, 313
Sand marl cement.....37
Sand, Marly.....8
- Sandstone.....310
Sandusky Cement Co.....296
Sanilac County.....231
Savicki, W. V.....341
Schimper.....78
Scirpus lacustris.....119
Schizothrix.....77, 90, 351
 aggregates.....236
Schloessing.....208, 209, 211
Sedimentary theory.....42, 44
Setting, Time of.....187
"Settle backs".....160
Seward.....78
Shabno's.....335
Shale.....149, 192, 321, 338, 342
Shells.....43
Shell deposit.....61
Shell theory.....41
Shell structure.....221
Shepard, W. H.....293, 294
Sherman.....329, 330, 331, 332
Sherzer, Will H.....312
Shiawassee County.....320
Shore wash, spoiling marl.....24
Siderite.....210
Silica, Effect of, on marl...36, 73, 192, 231
- See also ANALYSES.
- Silt, under water.....26
Silver Lakes.....276, 280, 290
Simons, W. H.....328
"Slag".....187
Slurry.....158, 176
Smeaton.....159, 355
Smith, F. L., & Company.....189
Snow, Dr. Julia W.....90
Sodium bicarbonate.....215
Solms-Laubach.....78
Solubility of gases in water.....208
Solubility, Point of.....45
Solubility of calcium oxide, etc... 212
Somers, J. H., Coal Company.....293
Soundings in lakes.....18, 19
South Bend.....162
South Island, Central Lake, Sec-tion across.....145, 146
South Lyon.....316, 320
Spaulding Township.....99
Species, list of.....101, 102
Specific gravity, Apparatus for making determinations.....362
Specific gravity and fineness.....187

Specifications for cement for Navy		T.	
Dept.....	186, 188	Tamarack log	29
Spring, deep	53, 62	Taylor, F. B.	321
Sulphur	132	Taylor's Landing	340
percentage of calcium and		Tensile strength of cement 232, 300,	368
magnesium in.....	46	Temperature, Average	216
Point of saturation of.....	45	Temperature of lake waters	51
Soft.....	62	Temperature of marl	286
water, hard	15	Temperature of wells	323
Characteristic of a marl		Tests, Analytical	71
region.....	23	Tests of cement 188, 232, 256, 257, 269,	
Spring Arbor	310, 352	281, 297, 300, 382	
Spring Lake	104	See Also ANALYSES.	
Springport	310, 335	Testing cement	181, 348 355
Squaw Lake	275	Tests, Tension	300, 378
St. Ignace	340	Texas, Kalamazoo County	310
Standard Portland Cement Com-		Three Rivers Cement Company ...	292
pany	168, 288, 289, 316	Tims Lake, Quantity of marl in 283,	286
Standiford Portland Cement Com-		Tompkins Township	310
pany	301, 303	Tooth and scouring powder, use of	
Stanger & Blount	175, 176	marl for.....	4
Stanley, J. S.	298, 330	Tourmaline	325
State Lumber Company	331	T. 1 N., R. 1 W.	307
Sterki, Dr. V.	98	T. 1 and 2 S., R. 4 E.	315
Stone	224	T. 2 N., R. 1 W.	307
Stone wall swamp	321	T. 2 S., R. 1 W.	310
Stoneworts	78	T. 2 S., R. 2 E.	283
Stony Point	340	T. 2 S., R. 18 W.	312, 314
Storage and packing	185	T. 2 and 3 N., R. 11 W.	317
Stowe, C. B.	283	T. 2 N., R. 5 E.	316
Straits of Mackinac	46	T. 2 N., R. 5 W.	310
Strawberry Lake	290	T. 2 N., R. 6 W.	310
Streams	25	T. 3 S., R. 7 W.	310
Strength, Compressive, of marl ...	183	T. 3 N., R. 18 W.	312
Highest.	182	T. 4 N., R. 6 E.	274
Tensile.....	183, 188	T. 4 N., R. 16 W.	312
Sturgis	313	T. 4 S., R. 11 W.	314
Succinic acid	88, 287	T. 4 S., R. 12 W.	314
Sulphate, Sodie or magnesia	210	T. 5 N., R. 7 E.	277
Sulphur spring	132	T. 6 N., R. 1 W.	313
Sulphuric and phosphoric acids,		T. 6 N., R. 2 W.	320
chlorine, etc.....	37	T. 6 N., R. 3 W.	313
Sulphuric acid 37, 50, 169, 170, 192,		T. 6 N., R. 5 W.	311
345, 361		T. 6 N., R. 12 W.	311
See also ANALYSES.		T. 7 N., R. 10 W.	311
Summerfield	312	T. 8 N., R. 8 W.	311
Surface	25	T. 8 S., R. 11 W.	291
Surfacing	169	T. 9 N., R. 9 W.	319
Surroundings of marl	23	T. 10 N., R. 11 W.	99
Susan Lake	81	T. 11 N., R. 5 E., Sec. 3.	99
Swain, Isaac N.	310	T. 11 N., R. 11 W.	99
Swan Creek	104		

399

Watervale.....	166, 297, 338	Willow Brook Farm.....	297
Wayne County.....	315	Wisconsin, Extension of marl in... 	6
Webster, John.....	322	Wolverine Portland Cement Com-	
Weed.....	65	pany	182, 246, 384
Wesenberg-Lund.....	68, 78	Woodstock	167, 228
West, Mr. F. E.....	88	Wyoming Township.....	319
West German Portland Cement			
Co.....	306		
Wetmore.....	20, 139	Z.	
Wexford.....	327, 329 332	Zenith Portland Cement Company	
Wheeler, Mr.....	104		282, 310
White Pigeon.....	103, 291	Zenotrichia.....	90, 91, 95
White River.....	307	See SCHIZOTHRIX.	
Whitney, H. K.....	301, 350	Zukey Lake	91, 168, 288

1

2

3

4

5

6

7

8

9

10

11



